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YELLOWSTONE-TONGUE A.P.O.

A WATER QUALITY MANAGEMENT PROJECT

GROUNDWATER REPORT

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Potential for ground water contamination



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POTENTIAL FOR GROUND WATER CONTAMINATION
FROM
PETROLEUM AND URANIUM EXPLORATION AND DEVELOPMENT ACTIVITIES:
ASSESSMENT AND RECOMMENDATIONS

FINAL REPORT

YELLOWSTONE-TONGUE APO
BROADUS, MONTANA

This report was financed by a
Section 208 Areawide Waste
Treatment Management Planning
Grant from the U.S. EPA.

PROJECT NUMBER 6023

JANUARY, 1978

**WILLARD OWENS
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SECTION I
INTRODUCTION

I. INTRODUCTION

PERSPECTIVE

In 1972 Congress passed, and the President signed into law, the Water Pollution Control Act Amendment. Section 208 of this law concerns "area-wide waste treatment management". Regional planning groups were authorized under Section 208 to provide comprehensive approaches to water quality improvement. The overall objectives of the law are to maintain good water quality, upgrade quality where necessary, and most importantly, plan to prevent future water quality problems to the best interest of individual streams, river basins, and the total environment.

A recent survey made by the National Water Well Association, including 150 Section 208 planning groups, discovered that nearly 80% of the "208" groups did not take adequate action with regard to ground water pollution related to waste disposal in their areas.

Fortunately, the Yellowstone Tongue planning group initially recognized the significance of potential ground water contamination in their Southeast Montana area. Because the exploration for oil, gas, and uranium are of significant importance in the area, efforts were undertaken to establish related potential for ground water contamination. In this regard, Willard Owens Associates, Inc., consulting engineers and ground water hydrologists, were engaged to provide an investigation of potential water quality problems related to the extraction of and

exploration for petroleum and uranium. The study was established to include exploratory drilling programs related to uranium, tertiary oil recovery processes, seismic exploration drilling, solution mining for uranium, and other related activities. This report is the product of that investigation.

LOCATION AND EXTENT OF AREA

The Yellowstone Tongue project area includes Carter, Custer, Fallon, Powder River, Rosebud, and Treasure counties and the northern Cheyenne reservation in southeastern Montana (Figure I-1).

GROUND WATER OCCURRENCE AND SIGNIFICANCE

The climate of southeast Montana is semi-arid. As is common in semi-arid regions, ground water is an extremely important natural resource and is widely used for domestic, stock, municipal, industrial, and irrigation purposes. In addition, the secondary recovery of petroleum and strip-mining of coal consume significant quantities of ground water.

Data compiled recently by the Montana College of Mineral Science and Technology show that there are approximately 6,000 wells in the Yellowstone Tongue project area averaging approximately 225 feet in depth. These data emphasize the shallow nature of most wells. Wells more than 300 feet are uncommon, although in east central Montana, some wells for domestic or stock purposes exceed 1,200 feet in depth.

Alluvial deposits of sand and gravel that occur along stream valleys are common sources of shallow ground water in the area. In addition, sandstone beds in the Arikaree formation, White River group, and the Wasatch formation yield locally-important but usually small quantities of water. The Fort Union formation occurs at the surface over 50% of the project area and contains sand beds and numerous, economically-significant beds of coal that may provide water of good chemical quality. The Hell Creek and Fox Hills formations underlie most of the area and are usually sought to

obtain greater amounts or softer water than that available from the shallower formations. Although older geologic formations, such as the Judith River, locally provide ground water, the potentially most significant deep aquifer is the Madison Limestone, which underlies the entire area at great depths (for example, the top of the Madison is about 4,000 feet below sea level, or about 7,000 feet below ground level, at Broadus, Montana). The Madison contains large quantities of water of commonly-good but highly-variable quality that is artesian (at Broadus, the potentiometric surface, which is the level that water would rise in a tightly-cased well, is about 500 feet above the land surface).

PETROLEUM AND URANIUM OCCURRENCE AND SIGNIFICANCE

Twenty-two oil fields have been discovered in the Yellowstone Tongue project area (Table I-1). One new field, the Breed Creek, was discovered in September of 1976 in Rosebud county. In 1975, production from the six counties of the project area constituted 59% of the total Montana production, and reserves for the same area are 54% of the total Montana reserves. Thus, oil production from the Yellowstone Tongue project area is of great significance, considering that from all of Montana.

Of 248 wildcat wells drilled in Montana in 1976, only 29 were in the Yellowstone-Tongue project area, and only one of these was successful. Essentially the same percentage (11%) of the 538 development wells drilled in the state in 1976 were in the Yellowstone-Tongue area. These data indicate that the major emphasis on Montana exploration has shifted away from the project area, although some continued efforts are expectable.

Oil fields in the area occur as clusters in northwest Rosebud county, southeast Powder River county, and Fallon county (Figure I-2). The Bell Creek field dominates the group in Powder River county, and is the largest in the area. It is 15 miles long, 3.5 miles wide, and has 305 active producing and injection wells associated with six secondary recovery units. Bell Creek

production averaged approximately 24,000 barrels of oil per day in 1976. An enhanced recovery project, funded in part by ERDA, is in the early stages of testing at the Bell Creek field.

Historically, Colorado, Wyoming, New Mexico, Utah, Texas, and Nevada have been major targets for uranium exploration. Lesser emphasis in the past has been extended into evaluating uranium resources in Montana, North Dakota, and South Dakota. Due to the shortage of uranium (Figures I-3 and I-4), areas of past minor emphasis are becoming targets for more active uranium exploration.

During the course of our work, we reviewed numerous publications discussing uranium occurrence in southeastern Montana and contacted mining companies who have explored in the area to evaluate the potential uranium development in southeastern Montana. The results of our work indicate that presently the largest amount of interest is in the Fall River, Lance, and Dakota formations in the area around Alzada. Apparently Kerr-McGee, Mobil, and possibly Exxon have located deposits of sufficient grade that may show potential for mining.

A secondary area of importance is the Tertiary age sediments of the Fort Union and the Cretaceous age sediments of the Hell Creek and Fox Hills formations of the Powder River Basin. Widely spaced exploration has

occurred intermittently in these formations with no reported significant discoveries. Due to the similarity of the geology between the northern Powder River Basin of southeast Montana and that of the southern Powder River Basin will be further explored for uranium in the future.

Another area of interest is the lignitic coal deposits that are uranium bearing in Carter county, Montana. Several companies have studied the feasibility of removing uranium from the coal, although to date no practical method has been found to economically separate the two energy sources. The uranium normally occurs in an average concentrate of less than .01 percent uranium. Consequently, a large volume of coal must be mined and treated in order to remove the uranium. At this time, mining the uranium requires destroying the coal. If either the coal or the uranium could be a useable by-product of the other extraction, then mining of the uranium may be economical.

PURPOSE AND SCOPE

Activities related to the exploration for and development of uranium and petroleum involve the potential for polluting ground water supplies. Exploratory drill holes, of necessity, commonly penetrate those aquifers which provide water for private as well as municipal and agricultural purposes. Several methods of contamination of these aquifers are possible. If aquifer contamination does occur, health hazards may be created that may require years to alleviate or may never be rectified.

This investigation was established in order to examine problems associated with potential aquifer contamination in the project area and to develop recommendations for the prevention of future contamination. The study was set up to include but not be limited to the investigation of potential water quality problems related to well casing leaks, radioactive tracers, tertiary and secondary oil recovery techniques, pumping or flowing of saline water, seismic exploratory techniques, solution mining, and cross-contamination as the result of natural geologic factors which have been altered by man.

As the investigation developed, certain limitations were encountered. A paucity of necessary data existed. For example, no comprehensive summary or compilation of ground water in the project area was available. To alleviate this problem, the Yellowstone-Tongue APO engaged the Montana College of Mineral Science and Technology to compile a

comprehensive summary of ground water data, including water quality, for the entire area. Their first publication includes geologic maps, topographic maps, and maps showing well appropriation, depths and water levels, sodium adsorption ratios, and total dissolved solids. Supplement B of their study, which will provide water quality analysis showing all available information for each well, and especially the chemical data for each well, will not be released until later this year. Consequently, although the portion of the compilation which has already been released is an important contribution, it provides insufficient detail for an in-depth analysis of water quality or of other ground water characteristics. These data would be of great help in a comparison of aquifers and in the analyses of regional trends in water quality.

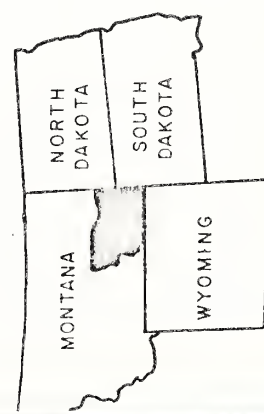
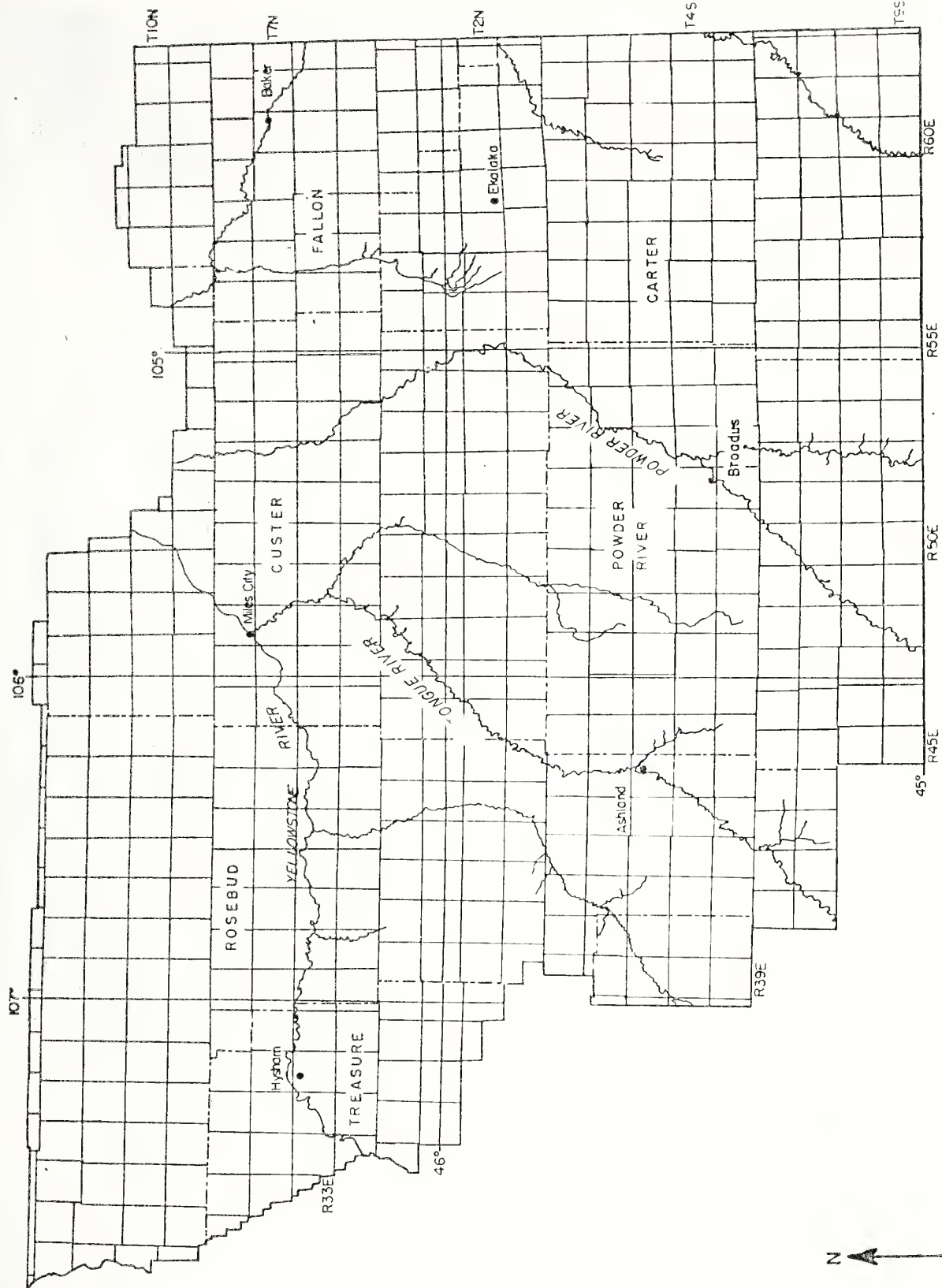
Another limitation in our investigation was that private mining and petroleum companies from the area were occasionally hesitant to release data and information concerning their programs because such data and information are considered proprietary. Consequently, most of our conclusions and recommendations are based on data and information which is available in public files, government reports, etc. As a result, our results occasionally may be considered out of date, considering the current status of industry knowledge concerning new techniques such as, for example, tertiary oil recovery techniques or solution mining techniques. However, we feel that adequate data

and information exist for the development of conclusions and recommendations which are of significance and will provide an adequate basis for the development of regulations with respect to these activities in the future.

ACKNOWLEDGEMENTS

We would like to express our appreciation to the personnel at Yellowstone-Tongue APO, who were always ready to be of help to us in our investigation, and especially to Clark Judy, Director. Paul Gipe of that organization was of significant help in collecting and developing data. Members of the principal state agencies of Montana, including the Montana Bureau of Mines and Technology, the Montana Oil and Gas Conservation Commission, the Montana Bureau of State Lands, the Montana Department of Health and Environmental Sciences, and the Department of Nautral Resources and Conservation were all of significant help. Personnel of federal government agencies included the U.S. Geological Survey, the U.S. Forest Service, and the Bureau of Land Management provided help. In addition, personnel from private companies engaged in petroleum, uranium exploration and development generously provided data and information that was not proprietary. These companies included Power Resources Corporation, Gary Operating Company, Halliburton Services, Baroid, and numerous companies exploring for uranium in the area.

Jon R. Ford, Nancy B. Lamm, Russell G. Shepherd, and Willard G. Owens contributed portions of this report.

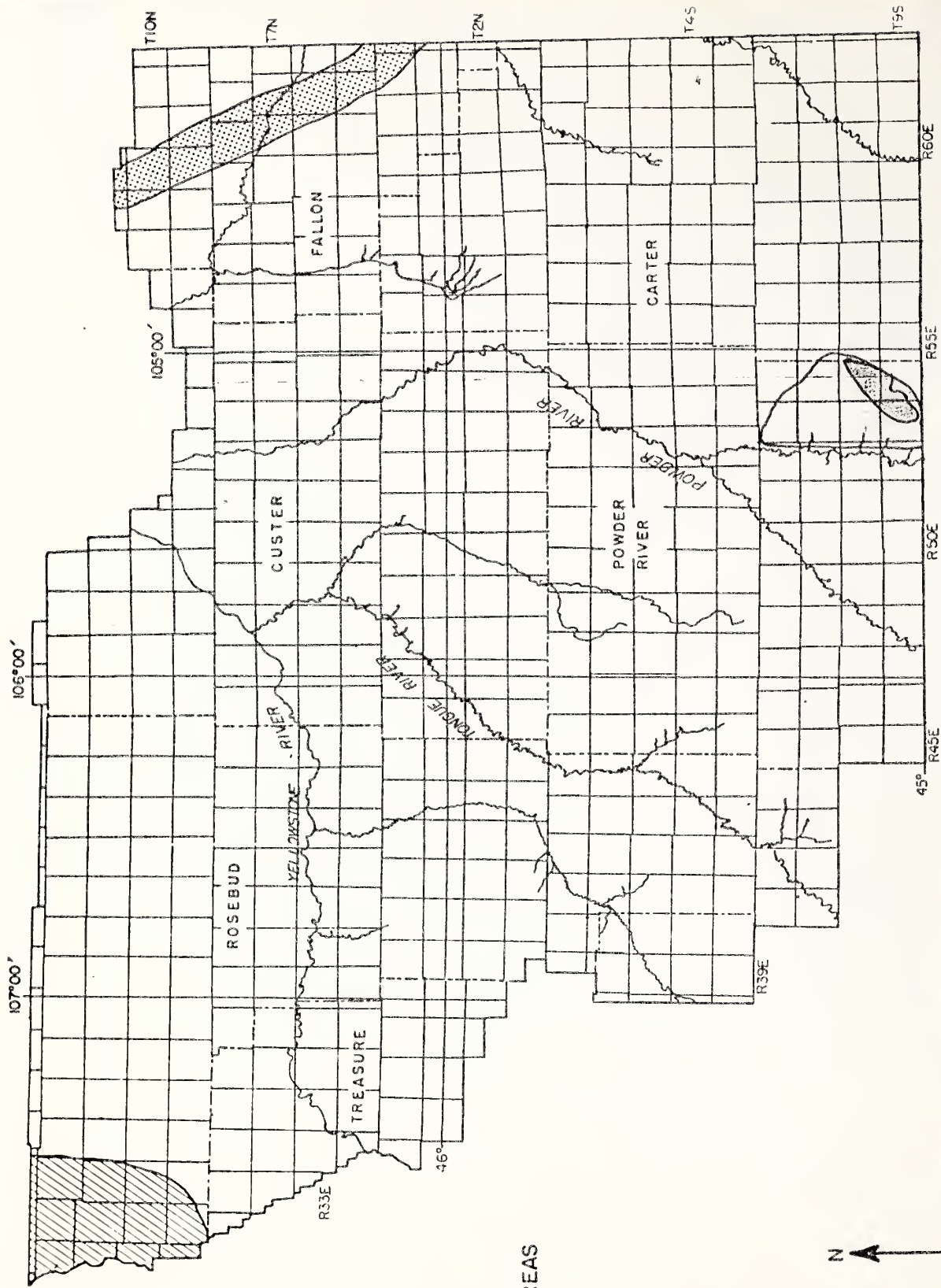






LOCATION MAP



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YELLOWSTONE TONGUE A.P.O.



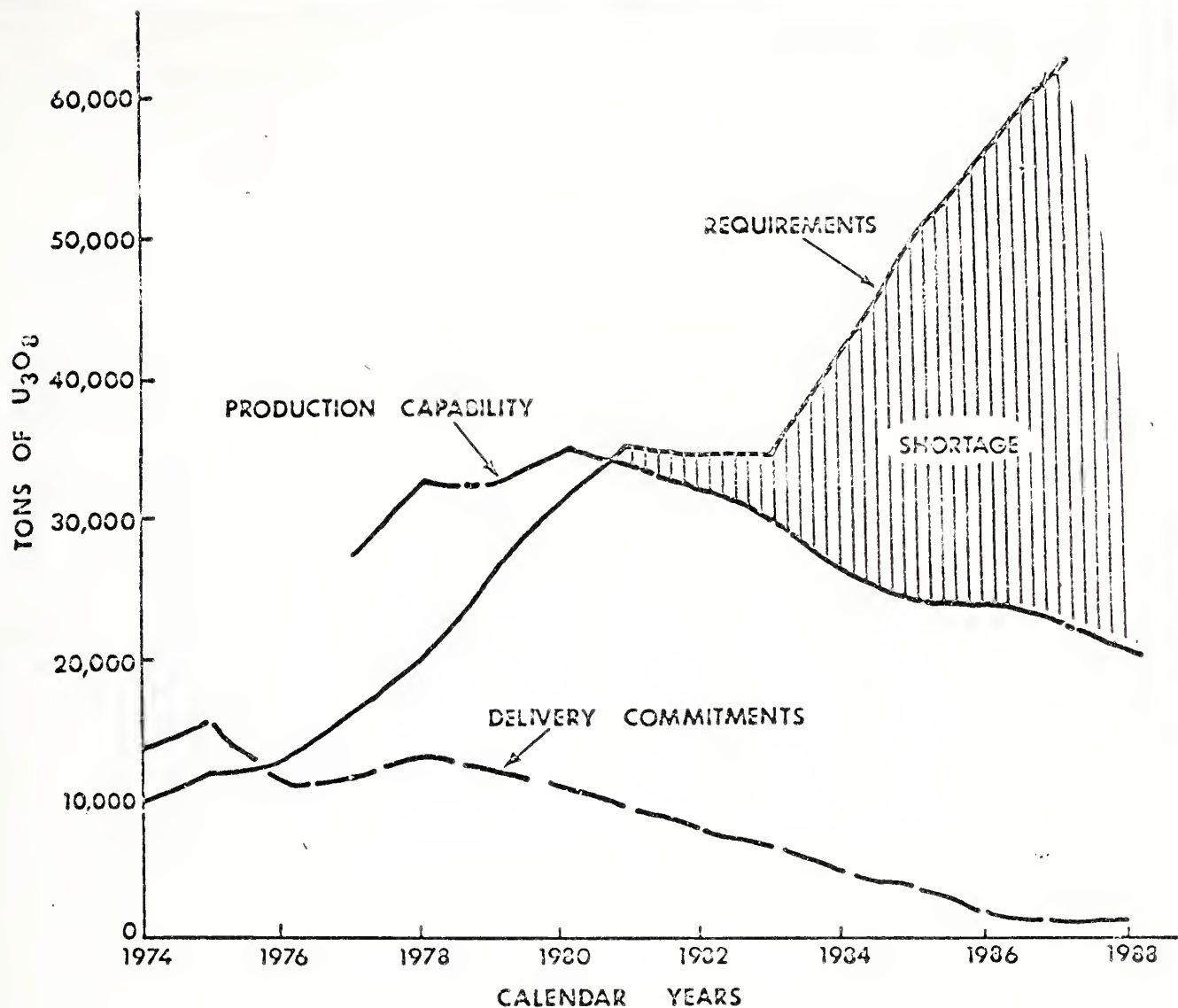
-  Bell Creek Oil Field
-  Cretaceous
-  Pennsylvanian
-  Ordovician - Mississippian

PRINCIPAL OIL - PRODUCING AREAS
AND FORMATIONS



From Montana Oil and
Gas Commission.





Maximum projected attainable production capability of all known uranium and potential uranium resources which can be considered economical at \$8/lb.

From Bobers 1975 and Patterson 1974

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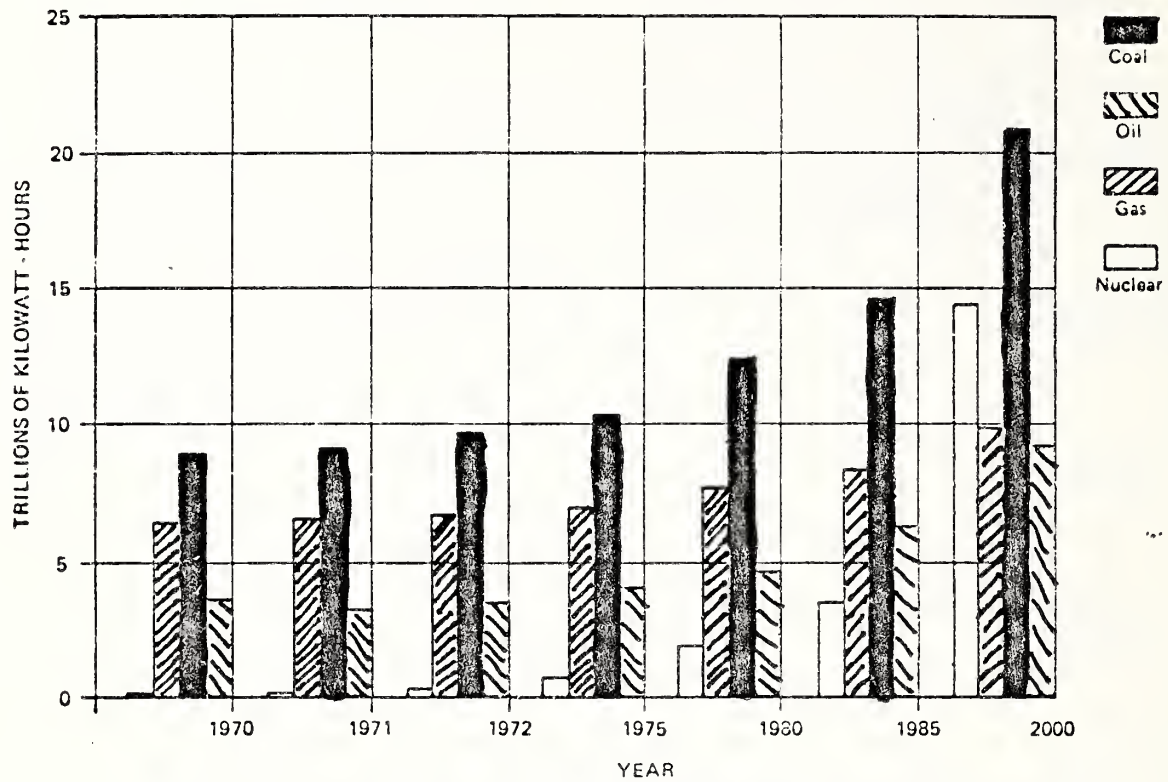


PROJECTED NATIONAL
URANIUM PRODUCTION

PROJECT NO. 6003

FIGURE I-3

ENERGY CONSUMPTION, ACTUAL AND PROJECTED, BY ENERGY SOURCE
(trillions of kwh)



SOURCE: STATISTICAL ABSTRACT OF THE UNITED STATES, 1974
UNITED STATES DEPARTMENT OF COMMERCE, PAGE 515

HISTORIC AND PROJECTED
NATIONAL ENERGY CONSUMPTION

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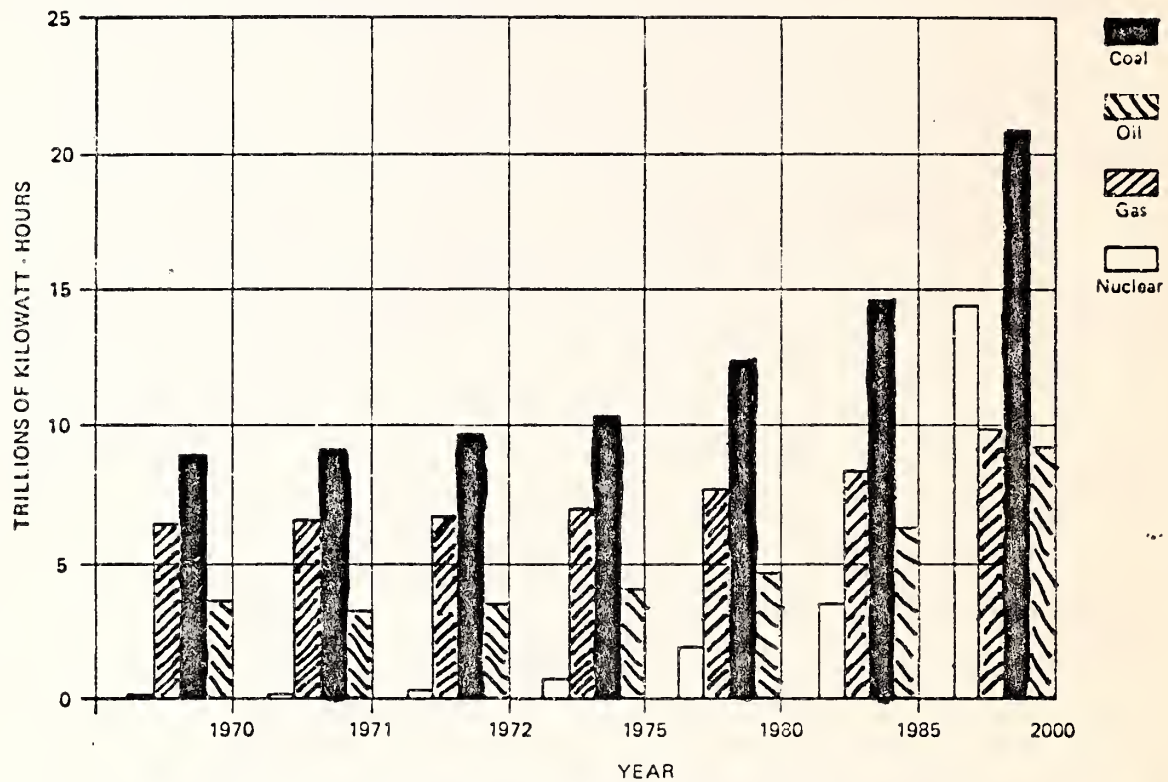
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LIST OF PRODUCING OIL FIELDS
 TONGUE PROJECT AREA, MONTANA
 Oil and Gas Conservation, Annual Review for 1975

DEPTH	PRODUCTIVE AREA 1-1-76 (acres)	CUMULATIVE PRODUCTION 1-1-76 (M BBLs.)	RESERVES 1-1-76 (M BBLs.)	1975 PRODUCTION (BBLs.)	1975 PRODUCTION (BOEPD)	ULTIMATE RECOVERY (BBLs./acre) (acre)	ULTIMATE RECOVERY (BBLs./acre) (acre/ft)
4,400	16,000	77,549	35,451	8,671,450	23,757	7,250	725
7,300	2,260	13,166	1,434	316,261	667	6,460	236
9,000	7,620	56,360	16,640	1,696,298	4,647	9,840	197
9,600	1,600	921	779	131,522	360	1,060	27
9,300	400	395	155	13,590	37	1,380	230
4,900	160	69	331	69,065	169	2,500	156
5,600	240	200	150	26,626	73	1,460	109
6,300	2,390	7,154	3,846	438,600	1,202	4,600	134
6,300	1,600	3,918	2,282	147,266	403	3,830	152
6,000	1,920	1,425	275	37,725	103	890	34
8,900	6,100	14,981	7,119	529,077	1,450	3,620	241
5,400	2,240	3,519	1,681	125,117	3-3	2,410	78
5,500	22,380	32,261	21,939	2,515,300	6,691	2,360	94
7,000	720					970	26
7,500	320					2,190	73
8,400	13,320	81,140	23,360	2,558,526	7,010	7,380	246
8,600	160	420	80	13,100	36	3,130	125
5,000	160	184	566	143,709	394	4,690	147
4,500	5,520	30,172	16,328	1,916,637	5,251	5,420	281
5,700	320	713	187	38,090	104	2,810	234
5,500	480	172	28	8,766	2	420	84
			135,331	19,396,793			



ENERGY CONSUMPTION, ACTUAL AND PROJECTED, BY ENERGY SOURCE
(trillions of kwh)



SOURCE: STATISTICAL ABSTRACT OF THE UNITED STATES, 1974
UNITED STATES DEPARTMENT OF COMMERCE, PAGE 515

HISTORIC AND PROJECTED
NATIONAL ENERGY CONSUMPTION

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PROJECT NO. 6023

SUMMARY OF PRODUCING OIL FIELDS
YELLOWSTONE - TONGUE PROJECT AREA, MONTANA
(From Montana Board of Oil and Gas Conservation, Annual Review for 1975)

FIELD	COUNTY	PRODUCING FORMATION	YEAR OF DISCOVERY	DEPTH	PRODUCTIVE AREA 1-1-76 (acres)	CUMULATIVE PRODUCTION 1-1-76 (M BBLs.)	RESERVES 1-1-76 (M BBLs.)	1975 PRODUCTION (BBLs.) (BOFD)		ULTIMATE RECOVERY (BBLs./ACRE)	(BBLs./ACRE/FT)
Bell Creek	Powder River	Muddy (Cret.)	1967	4,400	16,000	77,549	38,451	8,671,450	23,757	7,250	725
Cabin Creek	Fallon	Madison (Miss.)	1956	7,300	2,260	13,166	1,434	316,261	667	6,460	256
Catin Creek	Fallon	Siluro-Ordovician	1953	9,000	7,620	56,360	18,640	1,696,298	4,647	9,340	197
Cuption	Fallon	Red River (Ord.)	1955	9,600	1,600	921	779	131,522	360	1,060	27
Fertile Prairie	Fallon	Red River (Ord.)	1952	9,300	400	395	155	13,590	17	1,380	200
Gumbo Ridge	Rosebud	Tyler (Penn.)	1975	4,900	160	69	331	69,065	189	2,500	156
Leary	Powder River	Muddy (Cret.)	1969	5,800	240	200	150	26,626	73	1,460	109
Little Beaver	Fallon	Red River (Ord.)	1952	8,200	2,390	7,154	3,846	438,600	1,202	1,600	104
Little Beaver, East	Fallon	Red River (Ord.)	1954	8,300	1,600	3,918	2,282	147,268	403	3,850	162
Lookoutette	Fallon	Mission Canyon (Miss.)	1961	8,000	1,920	1,425	275	37,723	103	890	34
Lookout Butte	Fallon	Red River (Ord.)	1961	8,900	6,100	14,981	7,119	529,077	1,450	3,620	141
Monarch	Fallon	Siluro-Ordovician	1958	8,400	2,240	3,519	1,681	125,137	303	2,410	78
Pennel	Fallon	Siluro-Ordovician	1955	5,500	22,380	32,261	21,939	2,515,300	6,891	2,360	24
Pennel	Fallon	Mission Canyon (Miss.)	1957	7,000	720					970	26
Pennel	Fallon	Lodgepole (Miss.)	1960	7,500	320					2,190	73
Pine	Fallon	Siluro-Ordovician	1952	8,400	13,320	81,140	23,360	2,558,526	7,610	7,380	246
Repeat	Butter	Red River (Ord.)	1956	8,600	160	420	80	13,100	36	3,130	125
Rosebud	Rosebud	Tyler (Penn.)	1974	5,000	160	184	566	143,709	39	1,690	147
Sumatra	Rosebud	Tyler (Penn.)	1949	4,500	5,520	30,172	16,328	1,916,637	3,251	5,420	281
Willis Creek, East	Fallon	Interlake (Sil.)	1964	8,700	320	713	187	38,090	104	2,510	234
Wright Creek	Powder River	Muddy (Cret.)	1969	4,800	480	172	26	8,788	40	40	84
							133,331	19,396,792			

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SECTION II
GEOLOGIC SETTING

II. GEOLOGIC SETTING

PHYSIOGRAPHY

Southeast Montana is characterized by rolling upland plains that have been entrenched by several large streams and their tributaries. The Yellowstone River is the major drainage of the area and transects the project area from the southwest to the northeast (Figure I-1). Its principal tributaries on the south are Rosebud Creek, the Tongue River, and the Powder River. In the eastern portion of the area are many minor tributaries of the Little Missouri River. The Musselshell River cuts through the very northwest portion of the area. The physiography and classes of surface land forms are shown in Figure II-1.

CLIMATE

Typical of regions with semi-arid climates in the west, southeast Montana is characterized by pronounced changes and extremes of temperature, large diurnal changes in temperature, light precipitation (Figure II-2), low humidity, and much sunshine. Average runoff from the principal streams is low, as are the average discharges (Figure II-3 and II-4).

STRATIGRAPHY AND STRUCTURE

All of the bedrock units that outcrop in the Yellowstone Tongue area are sedimentary. They range in age from Early Cretaceous to Recent. However, the majority of the area is underlain by the Fort Union formation of Paleocene age.

The outcrop patterns of the principal sedimentary units (Figure II-5) are controlled by the major structural features of the area (Figure II-6). These structural features are the Black Hills Uplift, the Powder River Basin, the Cedar Creek Anticline, and the Porcupine Dome. Subsidiary structural features in the area are the Tongue River Syncline, the Ekalaka Syncline, the Plevna Anticline, the Miles City Arch, and the Sumatra Syncline. Where the strata have been upwarped to form a dome, anticline or an arch, older rocks are exposed at the center. From the center, the strata dip away towards the axis of these synclines or basins. Thus, near the center of the structural lows, the synclines or basins, the youngest rocks occur at the surface. These relationships are portrayed in east-west cross-sections through the northern and southern parts of the Yellowstone-Tongue project area (Figure II-7). Structure contours are shown in Figure II-8, and the stratigraphy is summarized in Figures II-9, II-10, and II-11.

Quaternary Deposits

Alluvial deposits of sand, silt, clay, and gravel are found throughout the study area in the valleys of the principal streams. Reworked terrace deposits characterized by coarse, well-rounded gravel occur along the Yellowstone River. Alluvial deposits are as much as 100 feet thick in the area. Other Quaternary deposits are dune sands and lacustrine deposits which occur in scattered local patches throughout the area.

Tertiary Deposits

The White River group was deposited during Miocene and Oligocene times. It ranges in thickness from 0 to 375 feet. It is composed of sandstones, shales, and impure limestones and capps high areas near Ekalaka. Its outcrop is limited in extent in the project area and it is not considered a major aquifer in southeast Montana.

The Wasatch formation, consisting of sandstone and interbedded shale and coal, has a thickness of 0 to 400 feet. Water yields from the Wasatch are fair and can be good if coarse-grained deposits are penetrated. The Wasatch was deposited during the Eocene times.

The Fort Union formation of Paleocene age, is comprised of three members and has a total thickness of 3,900 feet. The members are the Tongue River member, the Lebo shale member, and the Tullock member. This formation is comprised mainly of sandstones, shales, coal, and clinker

beds. Water can be obtained from the sandstone, coal, and clinker units. The water from the clinker beds is generally of highest quality. Clinker is formed when a coal bed burns and a baked or fused sandstone or shale results. Generally, this clinker has a high secondary porosity.

Cretaceous Deposits

The uppermost deposit of Cretaceous age in the study area is the Hell Creek formation. This silty sandstone, shale, and siltstone unit contains some thin coal beds and can be up to 850 feet thick. The upper portion of the Hell Creek is not considered an aquifer although the lower portion of the Hell Creek is generally grouped with the Fox Hills as an aquifer.

Underlying the Hell Creek formation is the Fox Hills sandstone. This sandstone represents the final marine deposit in the Yellowstone-Tongue area. Together with the lower portion of the Hell Creek formation, the Fox Hills represents a reliable source of water in the Yellowstone-Tongue area.

The underlying Pierre shale is a thick sequence of gray and black shales and claystones. The Pierre shale is not known to yield water. In the western part of the study area, however, the Pierre shale grades into five formations: the Bearpaw shale, the Judith River formation, the Claggett formation, the Eagle sandstone, and the Telegraph Creek formation. Of these formations, the Judith River formation and the Eagle sandstone are considered good aquifers.

Underlying the Pierre shale is the Colorado group, consisting of the Niabrara formation, the Carlile shale, the Greenhorn formation, the Belle Fourche shale, the Mowrey shale, the Newcastle sandstone, and the Skull Creek shale. None of these units are considered to be aquifers.

Of Lower Cretaceous age are the Dakota formation, the Kootenai formation, and the Lakota sandstone. These units consist of sandstones with some interbedded claystones and shales. The Dakota sandstone may yield some water and the Kootenai and Lakota sandstones yield some water.

Jurassic and Triassic Formations

The Morrison formation is of Jurassic age and is approximately 300 feet thick. This formation has a variable lithology that includes marls, limestones, and sandstones. The Morrison formation is not considered an aquifer in this area.

Underlying the Morrison formation are the Ellis group and the Chugwater and Spearfish formations. The Ellis group is generally shale with some limestone, sandstone, and gypsum. Some good water yields are found to the west of the study area. The Chugwater formation is located in the southwestern part of the area and is comprised of non-water bearing shale, sandstone, and anhydrite. The Spearfish is also non-water bearing and is comprised of siltstone, shale, and sandstone with interbedded salt, gypsum, and limestone.

Paleozoic Formations

Permian units underlying the study area consist of the Minnekahta limestone and the Opeche formation, neither of which are known to yield water. Pennsylvanian units are comprised of the Minnelusa sandstone which grades into the Tensleep and underlying Amsden formations to the west. These formations contain mainly sandstone with some dolomites and limestones. Water from these formations is slightly to very saline.

The Madison group comprises the Mississippian rocks underlying the Yellowstone-Tongue area, and is predominately limestones. Water yields are good although the water in some areas is saline.

Formations underlying the Madison group range in age from Devonian to Cambrian and generally do not appear to be significant aquifers in the Yellowstone-Tongue area.

GEOLOGIC HISTORY

During most of the Cretaceous Period, the Powder River Basin was covered by seas which were in regressive or transgressive phases. The final withdrawal of the sea took place during Late Cretaceous time and is represented by the Fox Hills sandstone. It is believed that the Fox Hills represents two separate regressive phases, the first phase being a slow and regular withdrawal, followed by a slight advance and then a final rapid withdrawal. Although some geologists correlate the regressive and transgressive phases of the sea during this time with the Laramide Orogeny, the absence of any coarse clastics in any of the units does not indicate any extensive uplifts in the western cordillera. It is believed that a broad regional uplift in central Montana was the cause of the final withdrawal of the Cretaceous seas.

The Hell Creek formation consists of vast amounts of continental deposits indicative of fluvial and lacustrine depositional environments. It is believed that during the Hell Creek deposition, the first indication of the Laramide Orogeny was seen as a relatively strong subsidence of the basin area. However, during the deposition of the Fort Union and Wasatch formations, the Laramide Orogeny was most pronounced.

During the deposition of the Fort Union sediment, the Big Horn Mountains and the Black Hills had begun to rise. In large volumes the sediments were being transported into the Powder River Basin. The environment of this basin was

mainly a swampy flood-plain environment. The extensive swamps that were present in this basin are now represented by coal beds found in the Fort Union formation.

It is believed that the Tullock and Lebo shale members of the Fort Union formation were indicative of this lacustrine deposition. Deposition was irregular and was not continuous throughout the area. During intervals of non-deposition, some erosion of the sediment took place.

This environment of deposition continued into the upper Paleocene. The Tongue River member of the Fort Union formation is characterized by alternating sandstone, siltstone, carbonaceous shale, coal, and clinker. This sequence of deposition is indicative of swamps and a period of alternating fluvial and lacustrine conditions.

By Eocene time, all the major structural features of the Powder River Basin area were present. The Wasatch formation was being deposited. Most present-day structural features of southeastern Montana were folded and faulted during early Eocene times. Deposition continued to be in an environment of fresh water lakes, streams, and swamps. During late Eocene times the Black Hills were uplifted and the Basin was tilted to the west, creating an asymmetrical structure.

Following this uplift, erosion further cut the landscape. During Oligocene and Miocene times, volcanic activity from the west buried much of the area in a layer of tuffaceous debris. Major regional uplift took place near the end of Pliocene time and extensive normal faulting

occurred. Another major regional uplift occurred near the end of Pliocene time and caused the streams to be rejuvenated and cut through the ash cover, and in the process, reexcavated some basins.

Local deformation and subsidence occurred with the burning of buried coal beds and the formation of clinker. However, this deformation was local.

Recent deposition has been alluvial, some eolian, and a limited amount of lacustrine.

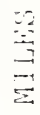
1. 20-50% of area gently sloping,
2. Local relief: 500-1000 ft.
3. 50-75% of gentle slope in lowlands

1. 50-80% of area gently sloping
2. Local relief: 300-500 ft.
3. 50-75% of gentle slope in lowlands

1. 50-80% of area gently sloping;
2. Local relief: 100-300 ft.
3. 50-75% of gentle slope in lowlands

1. 50-80% of area gently sloping;
2. Local relief: 300-500 ft.
3. 50-75% of gentle slope on upland

SEALING:



From RMAG, Geologic
Atlas of the Rocky
Mountain Region, and
U.S. Geological Survey,
Classes of Land Surface
Form

WILLARD COTTON
FABRIC COMPANY
INC.

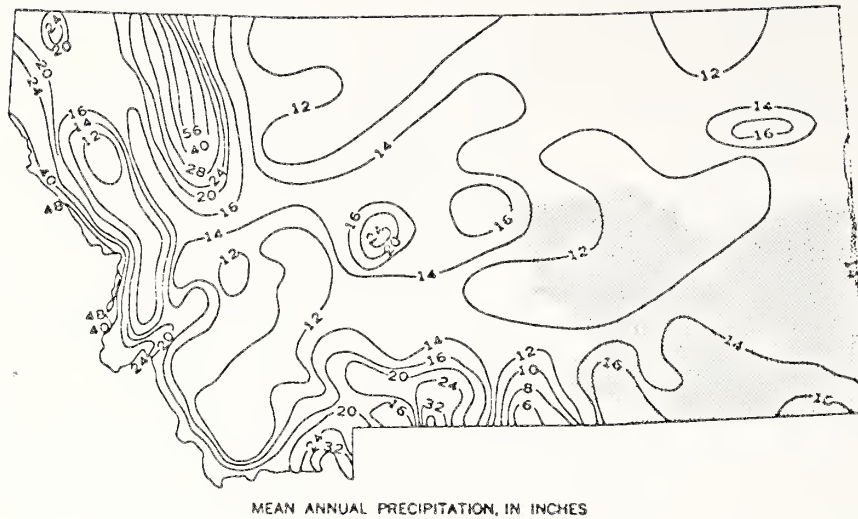


FIGURE II-2

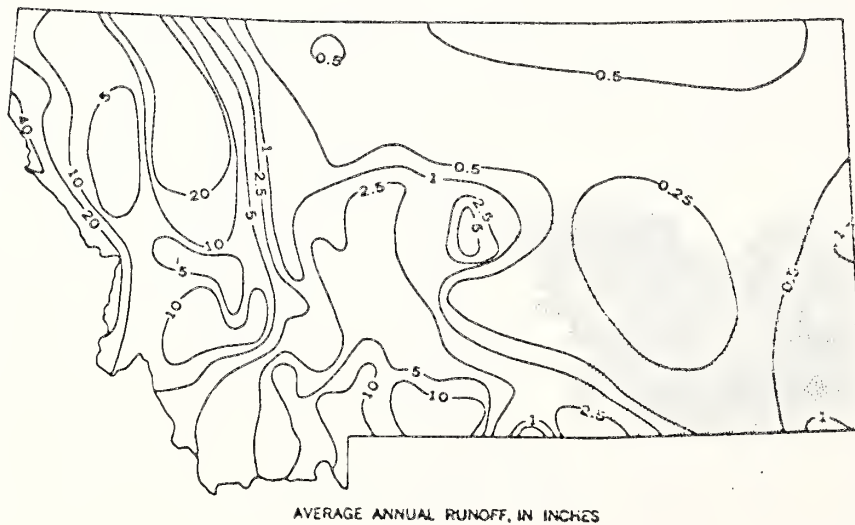
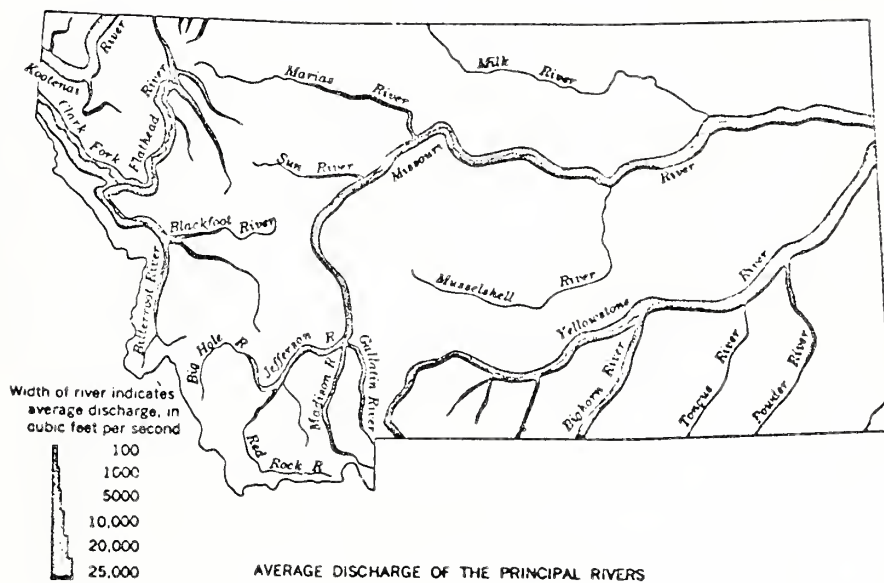


FIGURE II-3

From U.S. Geological Survey,
Water Resources Investigations
in Montana



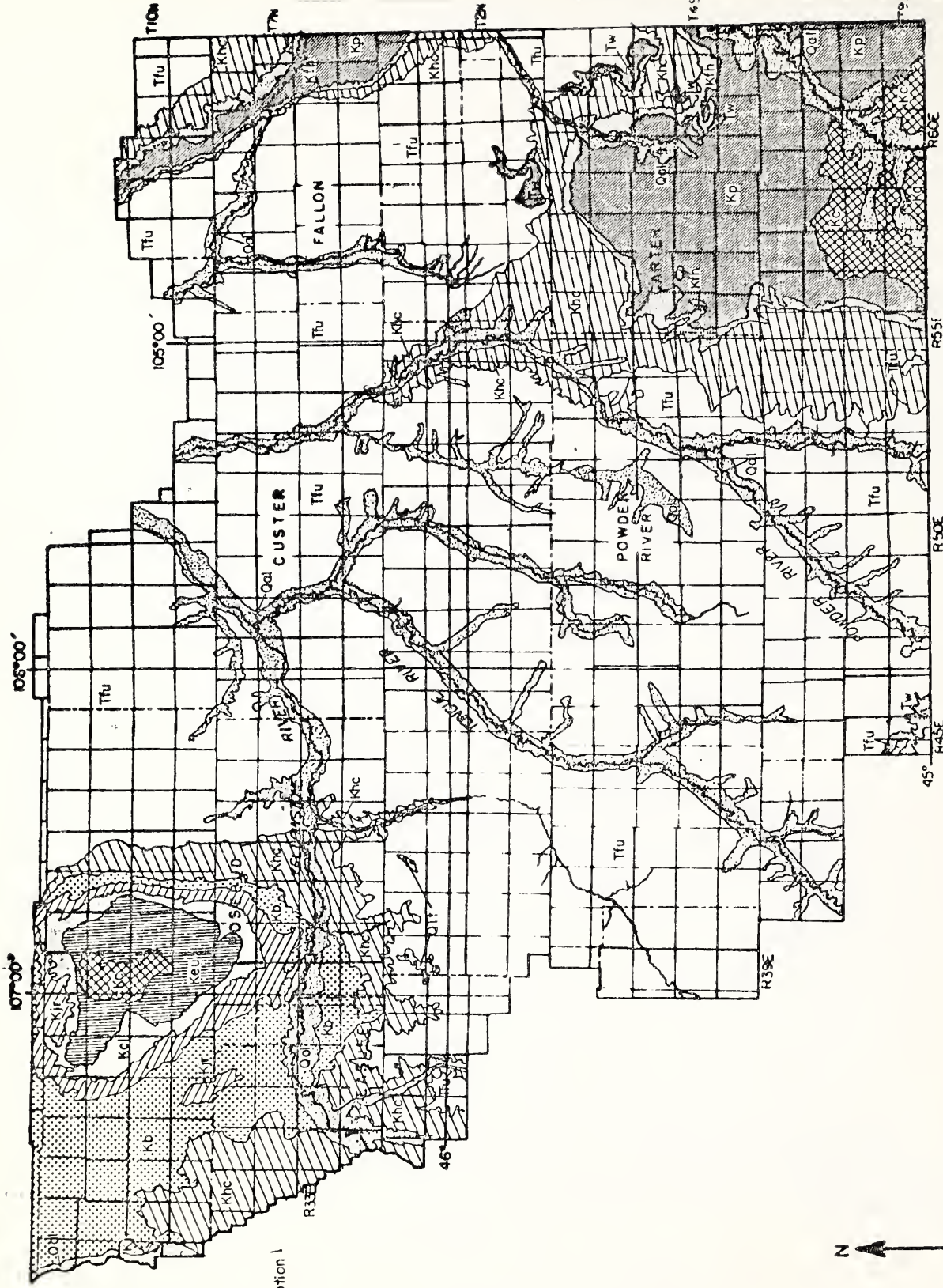
FIGURE II-2 and II-3



From U.S. Geological Survey,
Water Resources Investigations
in Montana

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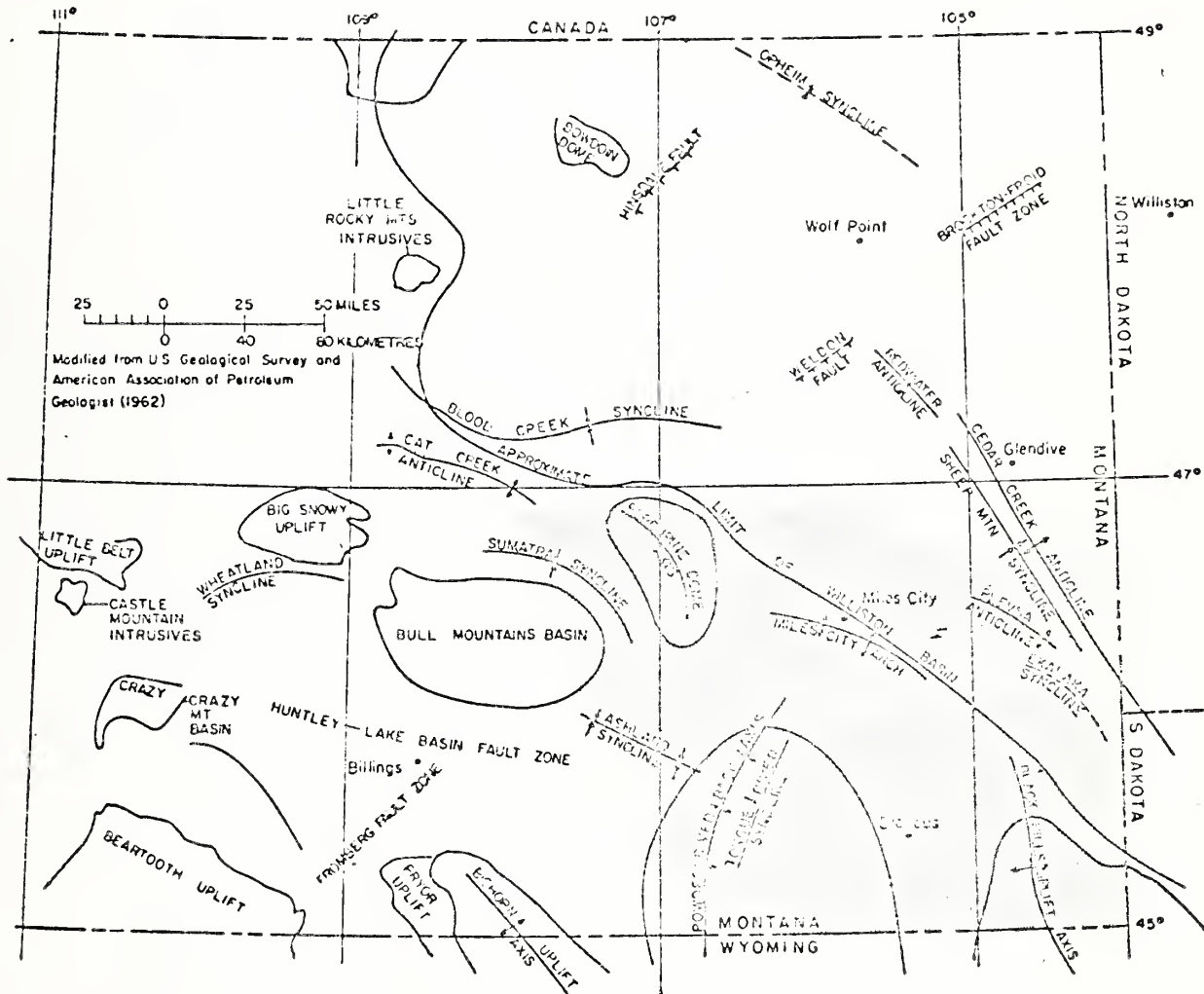


EXPLANATION	
QUATERNARY	
Alluvium	Qal
Terrace deposits	QTt
White River, Wosatch formation	Tu
Fort Union formation	Tfu
Hell Creek formation	Khc
Fox Hills formation	Kth
Bearpaw shale	Kb
Judith River formation	Kjc
Claggett formation	Kcl
Upper Eagle sandstone	Ksu
Pierre shale	Kp
Colorado shale	Kc
CRETACEOUS	



GEOLOGIC MAP YELLOWSTONE - TONGUE A.P.O.

MAJOR STRUCTURAL FEATURES YELLOWSTONE-TONGUE PROJECT AREA



From Hopkins, Water Resources Data for
Deep Aquifers of Eastern
Montana

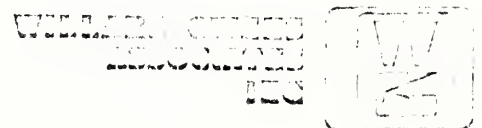
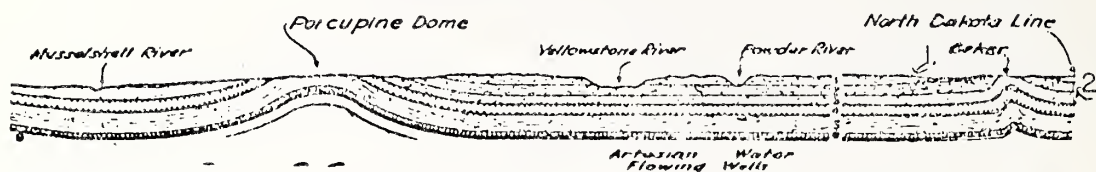


FIGURE II-6

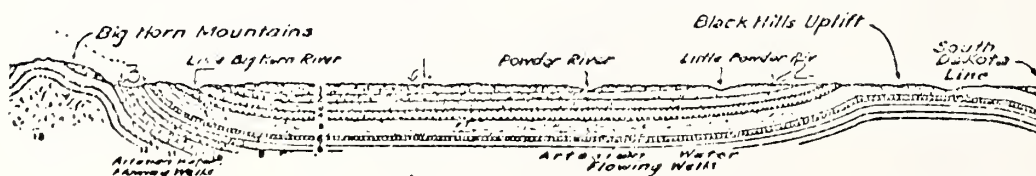
GEOLOGIC CROSS-SECTION YELLOWSTONE-TONGUE PROJECT AREA

EAST - WEST CROSS-SECTION FROM MUSSEL SHELL RIVER TO N.D. LINE



1. Fort Union Formation
2. Hell Creek, Fox Hills Formations
3. Madison Formation

EAST-WEST CROSS-SECTION FROM BIG HORN MTS. TO S.D. LINE



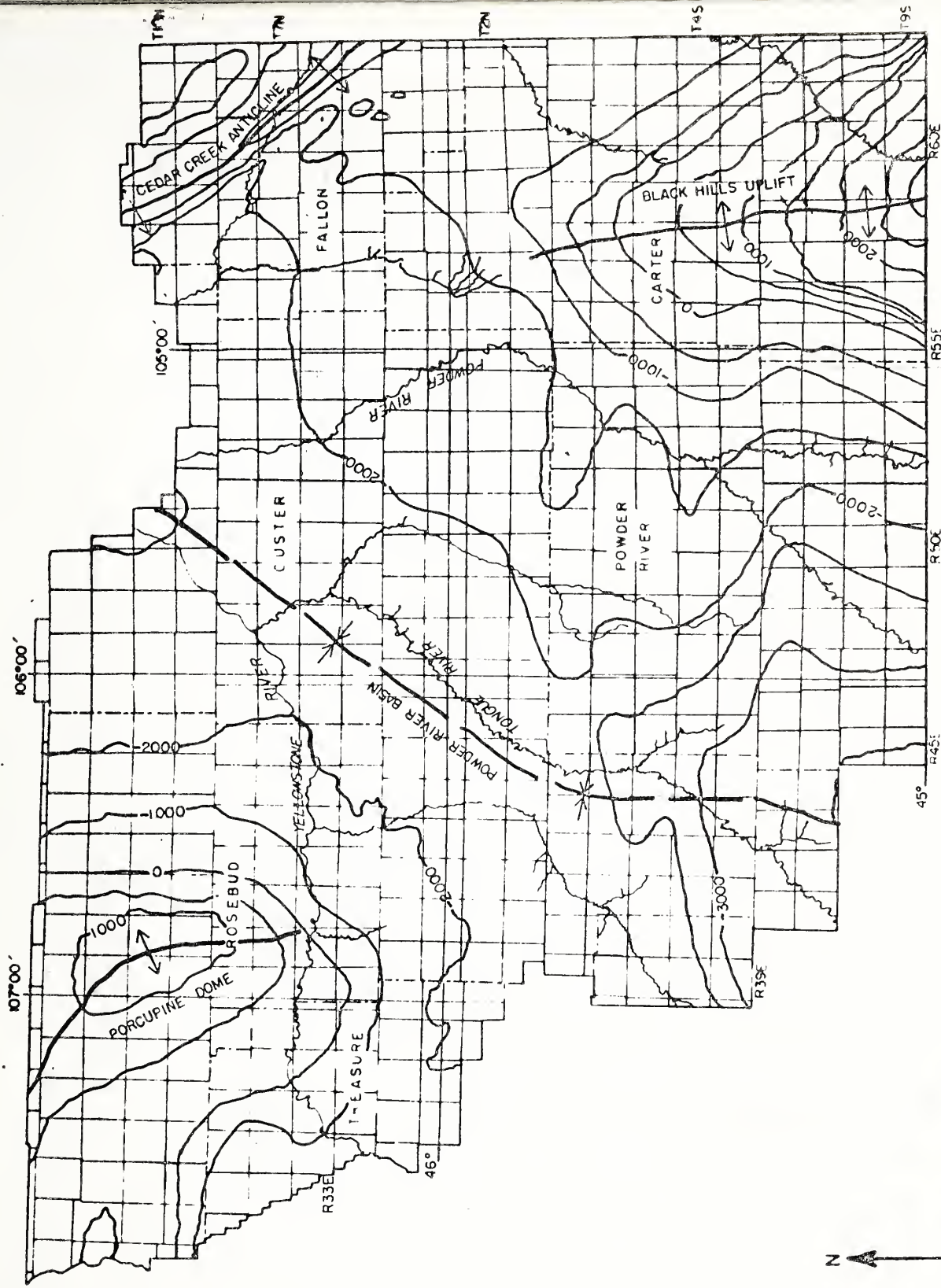
1. Fort Union Formation
2. Hell Creek, Fox Hills Formations
3. Madison Formation

From Perry, Ground Water in Eastern
and Central Montana

WILLARD GUNTER
GEOLOGICAL ENGINEER



FIGURE II-7



STRUCTURAL CONTOUR MAP
OF THE TOP OF
THE DAKOTA FORMATION

From Perry, 1931, Geology and Ground
Water Resources of Southeastern
Montana



YELLOWSTONE - TONGUE A.P.O.

TABLE OF GEOLOGICAL HISTORY

ERA	PERIOD	EPOCH	Absolute age in years before present	Major geologic events in United States given in order of increasing age	Distinctive features of plant and animal life	
CENOZOIC	QUATERNARY	Recent		Minor changes in land forms by work of streams, waves, wind	Rise of civilizations	Age of Man
		PLEISTOCENE	10,000	Four stages of spread of continental ice sheets and mountain glaciers	Development of man; extinction of large mammals	
	TERTIARY	PLIOCENE	1,000,000	Cascadian orogeny: Cascade and Sierra Nevada ranges uplifted; volcanoes built	Early evolution of man; dominance of elephants, horses, and large carnivores	Age of Mammals
		MIOCENE	12,000,000	Marine sediments deposited on Atlantic and Gulf coastal plain; stream deposits spread over Great Plains and Rocky Mountain basins; thick marine sediments deposited in Pacific coastal region	Development of whales, bats, monkeys	
		OLIGOCENE	25,000,000		Rise of anthropoids	
		Eocene	35,000,000		Development of primitive mammals; rise of grasses, cereals, fruits	
		PALEOCENE	60,000,000		Earliest horses	
			70,000,000	Laramide orogeny: Rocky Mountains formed		
MESOZOIC	CRETACEOUS			Marine sediment deposition over Atlantic and Gulf coastal plain and in geosyncline of Rocky Mountain region	Extinction of dinosaurs; development of flowering plants	Age of Reptiles
	JURASSIC		130,000,000	Nevadian orogeny: Intrusion of batholith of Sierra Nevada region		
				Marine sediment deposition in seas of western United States; desert sands deposited in Colorado Plateau	Culmination of dinosaurs; first birds appear	
	TRIASSIC		165,000,000	Polisadian disturbance: Black faulting in eastern United States		
				Deposition of red beds in fault basins of eastern United States and in shallow basins of western United States	First dinosaurs; first primitive mammals; spread of cycads and conifers	
PALEOZOIC	PERMIAN		200,000,000	Appalachian orogeny: Folding of Paleozoic strata of Appalachian geosyncline	Conifers abundant; reptiles developed; spread of insects and amphibians; trilobites become extinct	Age of Amphibians
				Deposition of red shales and limestones in southwestern United States; much salt and gypsum (glaciation of southern hemisphere continents)		
	CARBONIFEROUS	PENNSYLVANIAN	235,000,000		Widespread forests of coal-forming spore-bearing plants; first reptiles; abundant insects	
		MISSISSIPPIAN	260,000,000		Spread of sharks; culmination of crinoids	
	DEVONIAN		285,000,000	Acadian orogeny: Folding and igneous rock intrusion in New England	First amphibians; many corals; earliest forests spread over lands	Age of Fishes
				Deposition of thick marine strata in geosynclines of eastern and western United States	First land plants and air-breathing animals; development of fishes	
	SILURIAN		325,000,000			Age of Marine Invertebrates
	ORDOVICIAN		350,000,000	Taconian orogeny: Folding of rocks in eastern United States, Nevada, and Utah	Life only in seas; spread of molluscs; culmination of trilobites	
	CAMBRIAN		410,000,000		Trilobites predominant; many marine invertebrates	
			500,000,000			
	Pre-Cambrian time; age goes back to nearly three billion years			Many periods of sediment deposition alternating with orogeny	Earliest known forms of life; few fossils known	

From Strahler, Physical Geography, 1959

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FIGURE II-9

MESOZOIC

Cretaceous

Upper Cretaceous

Fm. Unit	Lk. St.	Thick. Member	Description	Remarks
Fox Hills Sandstone		0-280'	Near-shore sand facies that is the last marine deposit in the area. Two members are recognized: Colgate member -- very light gray fine-to medium-grained massive member. Unnamed lower member -- gray to brownish-gray fine-grained thin-bedded sandstone interbedded with gray sandy shale and siltstone. Lower contact is gradational, considered to be the base of transition zone between sandstone above and shale underlying unit. Conformable contact with underlying unit.	Lower Hell Creek and Fox Hills sandstone considered to represent one aquifer in the study area. Reliable source of water for artesian wells, yields as much as 20 gal/min. to flowing wells along the Tongue and Powder River valleys. Yields as much as 70 gal/min. to domestic and stock wells and 200 gal/min. to industrial wells.
Hell Creek Formation		0-550'	Gray to yellowish-gray silty, clayey, sandy, carbonaceous and bentonitic shale and siltstone, locally yellowish-gray to tan, fine-to medium-grained siltstone containing thin coal beds predominates. Lower contact is gradational, mapped as the change from predominantly silty shale and siltstone to predominantly sandstone of underlying unit. Contact probably unconformable with underlying Fox Hills sandstone and Bearpaw shale.	Upper Hell Creek limited as a water supply in study area, a few flowing wells yield as much as 4 gal/min.
Pierre Shale		500'-700'	In southeastern Montana, grades into Pierre shale.	Not an aquifer
		<400'	Interbedded shale and sandstone containing scattered thin coal beds.	Dependable aquifer in western part of area; wells yield less than 10 gal/min. of sodium bicarbonate type water. In eastern part of the area yield is smaller as sandstone grades into Pierre shale. Oil-field water from Judith River formation is principally sodium chloride or sodium sulfate type.
		400'	Predominantly shale containing scattered sandstone lenses. In eastern part of area, grades into Pierre shale.	Water in the sandstone is usually too highly mineralized for domestic or stock use, except in outcrop areas.
		<200'	Mostly sandstone; interbedded shale and lignitic beds in upper part.	In western part of area, the Eagle, particularly the Virgelle Member, is a reliable source of fresh to slightly saline sodium bicarbonate water. Well yields are less than 10 gal/min. Yield is reduced as sandstone grades into Pierre shale in eastern part of State.
		300'	Sandy shale and sandstone.	Water is too highly mineralized for domestic supplies.
		100'-200'	Marl, shale, shaly limestone.	Not an aquifer.
Colorado Group		up to 650'	Silty and sandy bentonite shale.	Not an aquifer.
		300'	Calcareous shale, shaly marl, and limy sandstone	Not known to yield water to wells in the study area.
			Principally shale containing thin beds of sandstone.	Confining beds.
		500'-600'	Belle Fourche Shale	
		125'-250'	Mowry Shale	
			to predominantly fine-grained sandstone and shale of underlying unit. Conformable contact with underlying unit, however, the Lebo exists locally as scoured channel deposits developed well into the Tullock member.	

Figure II-11

STRATIGRAPHY AND WATER YIELDING CHARACTERISTICS OF LITHOLOGIC UNITS OF THE YELLOWSTONE-TONGUE PROJECT AREA (CONT.)

MESOZOIC	Cretaceous	Lower Cretaceous	Colorado Group	Newcastle Sandstone	500'-800'	In the northwest part of study area, the Thermopolis shale is from 500 to 800 feet thick and includes the Muddy Sandstone member, which is from 50 to 125 feet thick. In southeastern part of study area, the Thermopolis grades into Newcastle Sandstone and Skull Creek shale.	Saline water.	
			Dakota	Skull Creek Shale	50'-160'	Sandstone containing minor amount of interbedded shale.	May contain water.	
			Fuson (Kootenai)		300'-600'	Kootenai formation is composed of sandstone beds and interbedded claystone.	Limited generally to western part of study area, where it yields less than 35 gal/min. water to wells. Fuson shale not known to yield water to wells.	
			Lakota Sandstone		10'-200'	Sandstone, conglomeratic sandstone, and shale.	Third Cat Creek and Lakota sandstone contain sodium bicarbonate and sodium chloride bicarbonate types of water in the Cat Creek area, Petroleum County. Yield more than 1,000 gal/min. to wells locally.	
			Third Cat Creek		10'-200'			
	Jurassic	Upper	Morrison Formation		300'	Variable lithology; includes marl, limestone, sandstone.	Potential yield unknown.	
			Ellis Group	Swift Rierdon Piper	750'	Subdivided (descending) into Swift, Rierdon, and Piper formations; formations principally shaly; locally limestone, sandstone, or gypsum present.	Piper contains highly mineralized water; Swift yields good water west of study area. Sundance and Gypsum Spring formations not known to yield water to wells in study area.	
	Triassic	Lower	Chugwater Formation		Variable	Chugwater formation is limited to southwestern part of area; generally non-water-bearing shales, sandstones, and anhydrite. Thicknesses variable.	Non-water bearing.	
			Spearfish Formation		350'	Spearfish formation includes shale, siltstone, and sandstone; interbedded salt, gypsum, and limestone.		
	PALEOZOIC	Permian		Minnekahta Limestone		up to 50'	Thin-bedded limestone.	Saline water.
				Opeche Formation		<130'	Shale, shaly sandstone, and sandstone.	Not known to yield water to wells.
		Pennsylvanian		Minnelusa Sandstone		300'	Tensleep grades laterally into Minnelusa sandstone in eastern part of Montana. Tensleep sandstone - fine-to medium-grained sandstone with some dolomite. Amos formation - sandstone, shale, dolomite, and limestone. Minnelusa formation - interbedded sandstone, sandy dolomite, and limestone with shale and siltstone.	Slightly saline to very saline but usable for irrigation.
				Ansden Tensleep				
		Mississippian		Charles Formation				
				Mission Canyon Limestone		2,200'	Madison Group is divided (descending) into Charles formation, Mission Canyon limestone, and Lodgepole limestone. The group is predominantly limestone, but the Charles includes salt, anhydrite, dolomite, and shale beds.	To the northwest of the study area, water in the Charles and Mission Canyon is saline. In the southern part of the area, the Mission Canyon limestone yields as much as 875 gal/min. to wells. The Mission Canyon is potentially a major aquifer where solution openings have produced high permeability. Lodgepole limestone yields 1,390 gal/min. of moderately saline water to wells near Porcupine Dome.
Devonian			Jefferson Group				Ground water yields unknown.	
			Interlake				Ground water yields unknown.	
Ordovician			Stoney Mountain			dolomite	Ground water yields unknown.	
			Red River			limestone	Ground water yields unknown.	
			Bighorn Dolomite			Fine to coarse-grained sandstone overlain by massive to thin-bedded dolomite.	Ground water yields unknown.	
			Winnipeg			Siltstone and shale.	Ground water yields unknown.	
Cambrian			Deadwood			Sandstone, shale, siltstone, and limestone.		
Sources: Hydrologic Investigations Atlas, HA-465 (USGS) by Hodson, Pearl, Druse, 1973. USGS Open File Report, Water Resources Data for Deep Aquifers of Eastern Montana, by Hopkins, 1976. USGS Open File Report Geology and Ground Water Resources of Southeastern Montana, Perry, Montana Bureau of Mines Memoir No. 14, 1935 Petroleum Geology of the United States, Landes, Wiley Interscience, 1970. Other miscellaneous documents.								

WILLARD OWENS ASSOCIATES INC

FIGURE II-11

FIGURE II-11



STRATIGRAPHY AND WATER YIELDING CHARACTERISTICS OF LITHOLOGIC UNITS OF THE YELLOWSTONE-TONGUE PROJECT AREA (CONT.)

MESOZOIC	Cretaceous	Lower Cretaceous	Colorado Group	Newcastle Sandstones	500'-800'	In the northwest part of study area, the Thermopolis shale is from 500 to 800 feet thick and includes the Muddy Sandstone member, which is from 50 to 125 feet thick. In southeastern part of study area, the Thermopolis grades into Newcastle Sandstone and Skull Creek shale.	Saline water.	
			Dakota		50'-160'	Sandstone containing minor amount of interbedded shale.	May contain water.	
			Fusion (Kootenai)		300'-600'	Kootenai formation is composed of sandstone beds and interbedded claystone.	Limited generally to western part of study area, where it yields less than 35 gal/min. water to wells. Fusion shale not known to yield water to wells.	
			Lakota Sandstones		10'-200'	Sandstone, conglomeratic sandstone, and shale.	Third Cat Creek and Lakota sandstone contain sodium bicarbonate and sodium chloride bicarbonate types of water in the Cat Creek area, Petroleum County. Yield more than 1,000 gal/min. to wells locally.	
			Third Cat Creek		10'-200'			
	Jurassic	Upper	Morrison Formation		300'	Variable lithology; includes marl, limestone, sandstone.	Potential yield unknown.	
			Swift					
		Middle	Rierdon		750'	Subdivided (descending) into Swift, Rierdon, and Piper formations; formations principally shaly; locally limestone, sandstone, or gypsum present.	Piper contains highly mineralized water; Swift yields good water west of study area. Sundance and Gypsum Spring formations not known to yield water to wells in study area.	
			Piper					
	Triassic	Lower	Chugwater Formation		Variable	Chugwater formation is limited to southwestern part of area; generally non-water-bearing shales sandstones, and anhydrite. Thicknesses variable.	Non-water bearing.	
			Spearfish Formation		350'	Spearfish formation includes shale, siltstone, and sandstone; interbedded salt, gypsum, and limestone.		
	PALEOZOIC	Permian		Minnekahta Limestone		up to 50'	Thin-bedded limestone.	Saline water.
				Opeche Formation		<130'	Shale, shaly sandstone, and sandstone.	Not known to yield water to wells.
		Pennsylvanian		Minnelusa Sandstone		300'	Tensleep grades laterally into Minnelusa sandstone in eastern part of Montana. Tensleep sandstone - fine to medium-grained sandstone with some dolomite. Amesden formation - sandstone, shale, dolomite, and limestone. Minnelusa formation - interbedded sandstone, sandy dolomite, and limestone with shale and siltstone.	Slightly saline to very saline but usable for irrigation.
Amesden Tensleep								
			Tyler Formation					
			Charles Formation					
Mississippian			Madison Group		2,200'	Madison Group is divided (descending) into Charles formation, Mission Canyon limestone, and Lodgepole limestone. The group is predominantly limestone, but the Charles includes salt, anhydrite, dolomite, and shale beds.	To the northwest of the study area, water in the Charles and Mission Canyon is saline. In the southern part of the area, the Mission Canyon limestone yields as much as 875 gal/min. to wells. The Mission Canyon is potentially a major aquifer where solution openings have produced high permeability. Lodgepole limestone yields 1,390 gal/min. of moderately saline water to wells near Porcupine Dome.	
Devonian			Jefferson Group				Ground water yields unknown	
Silurian			Interlake				Ground water yields unknown.	
Ordovician			Stoney Mountain			dolomite	Ground water yields unknown.	
	Red River				limestone	Ground water yields unknown.		
	Bighorn Dolomite				Fine to coarse-grained sandstone overlain by massive to thin-bedded dolomite.	Ground water yields unknown.		
	Winnipeg				Siltstone and shale.	Ground water yields unknown.		
Cambrian		Deadwood			Sandstone, shale, siltstone, and limestone.			
Sources: Hydrologic Investigations Atlas, HA-465 (USGS) by Hodson, Pearl, Druse, 1973. USGS Open File Report, Water Resources Data for Deep Aquifers of Eastern Montana, by Hopkins, 1976. USGS Open File Report Geology and Ground Water Resources of Southeastern Montana, Perry, Montana Bureau of Mines Memoir No. 14, 1935 Petroleum Geology of the United States, Landes, Wiley Interscience, 1970. Other miscellaneous documents.								

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FIGURE II-11

FIGURE II-11

SECTION III

FUNDAMENTALS OF GROUND WATER CONTAMINATION

III. FUNDAMENTALS OF GROUND WATER CONTAMINATION

GROUND WATER OCCURRENCE, MOVEMENT, AND DISTRIBUTION

Ground water is water stored in the minute openings between mineral grains of various formations or overlying soil. The role that ground water plays in the hydrologic cycle is illustrated in Figure III-1. Water resulting from precipitation and snow melt is either lost by evaporation or evapo-transpiration, occurs as surface runoff to larger bodies of water, or percolates through the ground surface and becomes ground water. Ground water moves beneath the land surface and can be trapped underground or recur at the surface in the form of springs or seeps. The study of ground water occurrence, movement, and distribution is known as hydrogeology, or ground water hydrology, and is a major field of study within itself. The following paragraphs will briefly summarize the major parameters concerning ground water hydrology.

OCCURRENCE OF GROUND WATER

Ground water originates as a result of the percolation of surface and atmospheric waters into the ground surface as illustrated by Figure III-1. Ground water occurs in formations known as aquifers which permit sufficient amounts of water to move through them under conditions such that the water is economically important.

Any portion of rock that is not occupied by solid matter is known as a void and may be occupied by ground

water. The degree to which these voids are occupied by ground water depends on their size, shape, voids, including pore spaces within individual grains, as in sedimentary rocks, and secondary voids developed after the rock was formed. Examples of these secondary voids include joints, fractures, and solution openings.

Aquifers consist of either consolidated or unconsolidated materials. Consolidated materials include geologic formations such as sandstones, conglomerates, and limestones. Unconsolidated aquifers are chiefly sands and gravels located along river beds, older fill in valleys, or surficial material covering plains. Water enters these aquifers from a natural or artificial recharge zone and flows from them under the influence of a hydraulic gradient, or head. Aquifers can cover many miles in extent or can be small perched aquifers above an impermeable layer.

The two types of aquifers of most concern in southeastern Montana are confined and unconfined aquifers (Figure III-2). A confined aquifer, also known as an artesian aquifer, is bounded above and below by impermeable beds or beds of distinctly lower permeability than that of the aquifer itself. An example would be a porous and permeable sandstone, overlain and underlain by non-permeable clay beds, in which the ground water is confined under pressure greater than atmospheric pressure. The level to which water in a tightly cased well in this aquifer would rise to is known as the piezometric surface. Where the land surface is

below the level of the piezometric surface and a well penetrates a confined aquifer, a flowing (artesian) well results. Southeastern Montana, because of its basin structure in the Powder River Basin, contains several important artesian aquifers.

An unconfined aquifer is one in which a water table serves as the upper surface of the zone of saturation and is not confined by an overlying strata. The water table varies in an unconfined aquifer depending on the permeability, previous pumping by wells, areas of recharge and discharge, and volume of water held in storage within the confined aquifer.

MOVEMENT OF GROUND WATER

In an area of ground water recharge, the initial movement of surficial water is downward into the soil until it reaches the water table or zone of saturation. At this point, the water tends to move more or less in a horizontal motion to areas where the zone of saturation has a lower elevation. Such movement is generally from higher elevations toward stream valleys. The water moves through permeable beds and flows parallel to the surface of impervious beds. Where the contact between the two beds encounters the ground surface, springs often occur. Springs such as these occur throughout much of eastern Montana, especially the outcrop areas of the Fort Union and Hell Creek formations. If, however, the rock strata through which the ground water is moving is inclined, the water will usually follow the dip of the bed and may flow in an opposite direction to the dip of the surface of the land.

The rate of movement of ground water depends on a wide range of parameters including the following:

1. Amount of pore space
2. Size of openings.
3. Shape of openings.
4. Connections between openings.
5. The weight of the water at a higher level in the same formation.

The amount of pore space depends on the size and shape of grains making up the aquifer, the most porous consisting of sand grains of the same size. If all else is equal, the water will move the fastest through the most permeable formation.

The size of openings depends on the size and shape of the mineral grains comprising the formation. If voids are extremely small, as in clay, water will be held within the formation and not be allowed to move. In addition, friction and capillary forces become important in small openings. If all other factors are equal, water will move more quickly through a coarse-grained formation than through a finer-grained formation.

The shape of the opening is important in that water will move most quickly through openings with equal dimensions. Fractures can have a wide lateral extent but be very narrow with enough friction to hold the water in place and prevent movement.

Openings must be connected to each other to allow movement of ground water. The size and shape of the opening depends on many factors, including the type of rock and types of cement in certain sedimentary rocks, such as sandstone.

GROUND WATER DISTRIBUTION

Ground water is likely to be found in many unconsolidated deposits and those consolidated deposits with sufficient pore space or interconnected fracture pattern to allow movement of water. Ground water is found in unconsolidated deposits consisting of valley fill, river alluvium, water saturated mass land movements, and alluvium covering wide spread areas such as alluvial fans and plains. Ground water is most likely to be found in consolidated deposits consisting of sands, gravels, sandy clays, and limestones. In crystalline rock such as igneous intrusives and metamorphics, ground water can occur in fracture zones and fault zones and in pegatite dikes. The amount of water located in such fractures and dikes, however, is probably minimal in most cases. Ground water is least likely to be found in consolidated units with a minimum of pore spaces such as clays or in massive unfractured rocks.

GROUND WATER QUALITY

There are many factors involved in the quality of ground water that should be considered in its use. The following topics cover some of the major facets of the chemical character of ground water. The U.S. Public Health Service has published a list of drinking water standards that are summarized in Table III-1.

Hardness

The degree of hardness of water can be seen by the amount of soap it takes to produce suds. This is the case because no suds will be produced until the minerals causing the hardness in the water have been removed by the soap. Almost all hardness of water is caused by calcium and magnesium in the form of mineral salts such as bicarbonates, sulfates, chlorides, and nitrates. Water with a hardness of less than 50 parts per million is considered soft and water with a hardness of 50 to 150 parts per million is considered suitable for most purposes. Water with a hardness of 200 to 300 parts per million should be softened for household use. Water having a hardness over 100 parts per million will deposit scale in steam boilers.

pH or Hydrogen Ion Concentration

pH is a measurement of the relative concentration of hydrogen ions in water and whether this water will act as a weak acid or as an alkaline solution. Pure water has

a pH of 7. Acid water has a pH lower than 7 and an alkaline solution has a pH greater than 7. Generally, the pH of most ground waters is governed by the amount of dissolved carbon dioxide gas and the dissolved bicarbonates or carbonates in the salt. Carboic acid is formed when carbon dioxide gas is dissolved in water and this acid, although weak, can lower the pH noticeably. If, however, an alkaline salt is present, the pH is not lowered appreciably by carboic acid. Most ground water in the U.S. has a pH range from about 5.5 to about 8. Any ground water with a pH lower than 4.5 probably contains free mineral acids. These acids can result from mine waters or contamination by industrial waste.

Total Dissolved Solids

The total dissolved solids is a measurement of the total amount of material dissolved in water. This measurement is a general indication of the suitability of water for various uses. Water containing less than 500 parts per million is generally considered satisfactory for domestic use, although, certain industrial uses might require water with a TDS less than 500 parts per million.

Iron

Although iron is found in practically all water supplies, the U.S. Public Health Service placed .3 parts per million as the upper limit of iron that can be in water used for domestic purposes. This limit does not necessarily reflect

the fact that greater amounts of iron would have an adverse effect physically on the body. Factors other than physiological are considered when this limit of iron is set. Iron in water can cause plugging of pipes and staining. Some industrial processes cannot use water with an iron content greater than .1 parts per million.

Iron commonly occurs in two ions, ferrous iron and ferric iron. Ferrous iron is more soluble in water than ferric iron and is also unstable in the air. When ground water containing ferrous iron comes into contact with the air, the ferrous iron oxidizes to the ferric state and precipitates out in the same compounds that we know as rust.

In addition, iron bearing waters favor the growth of bacteria which in turn, clog water mains and cut down on the flow rate of water through pipes. The presence of these organisms can change dissolved iron into the ferric state which in turn can clog the pores in water-bearing formations. These bacteria live in a dark environment with little or no oxygen.

Manganese

Manganese in water resembles iron to a great extent in that soluble manganos carbonate changes to insoluble manganese hydroxide upon contact with air. Manganese comes out of solution as a sooty material and also encourages the growth of a slime forming bacteria similar to iron bacteria which in turn causes oxidation of manganese compounds to an

insoluble form. Iron and manganese can be kept in solution by adding sodium hexametaphosphate to the water.

Silica

Small amounts of silica are found in ground water as the result of the weathering of silica bearing rocks. Silica in ground water is a problem if it is deposited as a calcium or magnesium silicate. As such, this comes out of the water as a very durable scale and cannot be dissolved by acids.

Sodium

Ground water containing large quantities of sodium carbonate or sodium bicarbonate are alkaline in nature and can have pH values of 9 or more. Sodium in water does not form scales.

Acidity

Acidity of water is the ability to neutralize a base. Mine waters commonly contain free mineral acids generally in the form of sulfuric acid. This acid is the result of a chemical change of iron pyrite and other metallic sulfides in which water and oxygen combine with the sulfide to form sulfuric acid. Free mineral acidity is only present when there is a pH below 4.5. This kind of free acid is generally found in mine areas such as coal mining and hard rock mining.

Chloride

Chloride is found in sea water with a content of approximately 19,000 parts per million. When a fresh water aquifer is being contaminated by sea water or brackish water, the chloride content rises. Water containing less than 150 parts per million of chloride is suitable for domestic purposes. A chloride content greater than 250 parts per million is unsuitable for a municipal water supply, and a chloride content greater than 350 parts per million is unsuitable for most industrial and irrigational uses. However, livestock can tolerate greater amounts of chloride and some believe that cattle can tolerate 3,000 to 4,000 parts per million chloride.

Fluoride

Fluoride is derived from the mineral fluorite found in igneous rocks or from any number of complex fluoride bearing minerals. Fluoride is generally found only in minute quantities in ground water. Standards for amounts of fluoride in water vary according to the temperature and are summarized in Table III-2. Large amounts of fluoride consumed by children can result in a mottled enamel on the teeth but smaller amounts of fluoride have been found to be beneficial to dental hygiene. The Public Health Service has set limits on the permissible amount of fluoride according to temperature to compensate for the amount of water consumed by children during warmer weather.

Nitrate

The U.S. Public Health Service has set 45 parts per million as a safe limit for nitrates in water used for domestic purposes. The presence of nitrate in ground water is a good indication of pollution from surficial water. Nitrate content is high in fertilizers, plant debris, and manure. Pollution from such sources as cesspools, feedlots, and barnyards can be indicated by a high concentration of nitrate. Under such circumstances, it is recommended to have the water tested for bacteria which also would be carried into the aquifer under such conditions.

Nitrates in concentrations greater than 45 parts per million can cause a disease in young infants known as cyanosis. Cyanosis causes an infant to become drowsy and listless, although excessive nitrate does not cause this disease in older children or adults. Nitrate can only be removed from water through distillation or by demineralization.

Sulfate

The Public Health Service has set a limit of 250 parts per million for sulfate content in water. Sulfate in sufficient quantities will result in a bitter taste in water and as a laxative for people not accustomed to drinking it.

Dissolved Gases

The presence of dissolved gases can affect the proposed uses of ground water. The most common dissolved gases are

oxygen, hydrogen sulfide, carbon dioxide, nitrogen, sulphur dioxide, and ammonia. In respect to the use of ground water, oxygen, hydrogen sulfide, and carbon dioxide are of greater significance. Solubility of gases increases with higher pressure and lower temperatures. Dissolved gases are often the cause of corrosion and deposition of incrustive materials.

Oxygen - Dissolved oxygen in water increases the corrosion effect of water upon iron, steel, brass, and galvanized iron. As the temperature rises, corrosion effect increases but the amount of dissolved oxygen decreases, so one effect counteracts the other effect. Water with a low pH attacks metal more readily than with a higher pH if the water contains dissolved oxygen. Dissolved oxygen attacks galvanized iron more quickly as the zinc of the galvanizing is oxidized and washed away. Dissolved oxygen can also remove zinc from brass alloys and results in a weakening of the metal.

Hydrogen Sulfide - Hydrogen sulfide in ground water is easily recognized by its rotten egg odor in quantities as small as .5 parts per million. Hydrogen sulfide in water forms a weak acid and is corrosive.

Carbon Dioxide - Carbon dioxide is found in ground water from two sources, it is picked up by rainfall as it passes through the atmosphere or by water flowing through soil containing plant roots and decaying vegetation. Especially significant is the presence of carbon dioxide

in ground water when calcium and bicarbonate are in solution. If sufficient pressure is present, the solution will be stable and the escape of carbon dioxide will be prevented. However, if the pressure of the aquifer is reduced by pumping, the carbon dioxide comes out of the solution and bubbles out as a gas. The equilibrium is thereby disturbed and the calcium carbonate precipitates until a new equilibrium is established, and results in a deposition of calcium carbonate.

Water Quality in Agriculture

The presence of various ions in the soil can change the basic characteristics of the soil. Clay with an excess of calcium or magnesium tills easily and has a good permeability. However, the presence of sodium causes the clay to become sticky and slick with a low permeability. A high concentration of sodium results in an alkali soil in which no vegetation will grow. It is beneficial for irrigation water to contain calcium and magnesium as these minerals will override the detrimental effects of sodium. A ratio to determine the amount of sodium in relation to calcium and magnesium in the soil is called the sodium adsorption ratio or SAR and is as follows:

$$SAR = \frac{\text{sodium}^+}{\frac{\text{calcium}^{++} + \text{magnesium}^{++}}{2}}$$

The value of 18 or more is considered high, values from 10 to 18 are medium, and any values below 10 offer little danger in sodium buildup.

MODES OF GROUND WATER CONTAMINATION

Contamination from the ground surface is probably the most common form of ground water contamination and can result from many sources such as leaks in pipelines and storage tanks or various spills. Surficial contamination can also be the result of infiltration from waste ponds, brine evaporation ponds, and contaminated lakes. Other sources not related to oil and uranium exploration are contamination from septic tanks, storm sewers, and land fills. Any potential contaminant in solid form stored on the land surface such as salt for de-icing can also be a potential contaminant of ground water.

Surficial contamination of ground water aquifers can begin as precipitation, percolate through the ground surface, reach the water table, and in the process leach out contaminants located on the ground surface. Such contaminants could be oil and gas from leaky pipelines, storage tanks, or spills or chemicals or other substances stored on the ground surface. An example is a salt stock pile used for de-icing streets, which is easily dissolved and washed into the ground water aquifer (Figure III-3).

Contaminated liquids stored on the ground surface, as in waste ponds and brine evaporation pools, can spread contamination into the ground water by percolation, through the recharge area of an aquifer, and into the ground water supply (Figure III-4). Other forms of contaminated water on the ground surface such as polluted

lakes and streams, act in a similar manner (Figure III-5). In relation to the oil exploration industry, evaporation ponds are especially hazardous as a source of ground water pollution.

Methods of preventing such ground water contamination depend on the nature of the contamination. Oil field evaporation ponds should be lined with an impermeable seal to prevent downward percolation of contaminants. Waste should not be left on the ground surface in such a manner that precipitation could dissolve some wastes and carry it to the ground water. Care must be taken to avoid contamination of lakes and ponds and streams as these can usually result in a direct contamination of the ground water. In addition, care must be taken in any storage or transportation of the potential contaminants in order to avoid any possible leaks or spills. Solid contaminants should not be stored on the ground surface but should be covered or sealed in an impermeable container.

Any well constructed, whether oil well or water well, is a possible source of contamination and pollution of ground water. Contaminants can enter from the ground surface or from other formations and travel inside or outside of the well casing. There are several ways that contaminants can enter from the surface: (1) contaminants can enter through or under the pump and go down the casing and out the perforations or (2) contaminants can enter

in the disturbed surface on the outside of the casing or enter in the gravel pack if it extends to the surface and seep to the aquifer (Figure III-6). Efforts should be made to maintain a tight seal at the surface of the pump, the casing, and the ground surrounding the well, in addition to the gravel pack being sealed beneath the ground surface.

When a well penetrates several aquifers, each with different hydraulic heads, contamination becomes possible within the well itself. Contaminants can enter the well through any openings in the casing and enter the desirable aquifer through the perforations. Openings may be a result of an improper welding, joint failure, pitting due to corrosion, poor seal, or a split seam. Contaminants can also enter the aquifer by seepage through the gravel pack if the gravel pack has not been securely sealed above the desirable aquifer. In this manner, polluted water simply percolates through the gravel pack down into the desirable aquifer. If several aquifers are penetrated by perforated casing, contaminants or poor quality water can flow by vertical flow from one aquifer into the next. This is the case when one aquifer has a higher or lower head of pressure than the other aquifer. Attempted sealing off a contaminated aquifer by the use of a liner can also fail if the contaminated aquifer has a head of pressure such that the water can flow between the liner and the casing up into the well and back down into the desirable aquifer. (Figure III-7)

-4-

During construction of a well, it is imperative that all aquifers be fully sealed from each other. Gravel packs should be grouted and no well should be allowed to draw water from more than one aquifer. Preliminary studies should be conducted to best determine the depth of the desired aquifer and the nature of the overlying aquifers. This information can be obtained by studying well logs of nearby wells. The well can then be adequately designed to effectively seal off any contaminated or undesirable aquifers that it penetrates.

Continued use of even a properly designed and constructed well can lead to contamination problems. Subsidence can occur from vibration or continued sand pumping (Figure III-8) and desiccation of the grout or cementing material can cause leakage, even in an effectively sealed well. Continued maintenance and observation of a producing well should be maintained so that problems resulting from continued use can be rectified.

Abandoned wells can be a further source of contamination. Corrosion of the well casing can lead to contamination of aquifers, and seals at the surface of the well can deteriorate, causing contamination from surficial sources. Whenever a well is abandoned, it is imperative to attempt to restore the geologic conditions as they were before drilling in as much as is possible.

Underground storage facilities which may appear to be an ideal location for storage of possible pollutants can result in contamination of ground water supplies. An example of this is the Herscher underground natural gas storage field located near the village of Herscher in Illinois. Natural gas was stored in a geologically closed anticline or dome that appeared to provide a geologic trap necessary for the large scale storage of natural gas. It appeared that a permeable sandstone was overlain by a dense and impermeable dolomitic sandstone which would form a seal over the storage formation. Gas was pumped into this permeable sandstone and approximately 4 months later began to bubble out in shallow ground water wells in the town of Herscher. One week later, a total of 33 water wells within the area became contaminated with natural gas. It is not known precisely what caused this migration of natural gas, although several theories include faulty well cementing, faulting, or lack of adequate caprock. Deep well injection of waste or storage of natural gas or oil is recommended only when all factors affecting possible leakage are understood and accounted for.

Overpumping of existing wells can also lead to contamination of ground water supplies. Overpumping occurs when fresh water is removed from an aquifer and underlying salty or otherwise non-potable water migrates upward into the fresh water aquifer. Further spreading of this non-potable water can occur into other aquifers through internal circulation in the well.

Contamination of fresh water aquifers through poorly-constructed or abandoned wells is a critical problem since generally, by the time of detection, the the ground water is already seriously polluted. Tracing the source of contamination is often difficult. Wells should always be properly designed and constructed and constantly maintained. Every attempt to prevent corrosion of the casing should be made. Common forms of corrosion

include general rusting or other uniform loss of metal, loss of one element of an alloy leaving a weakened residue, corrosion near the junction of two different metals, localized pitting, stress-corrosion cracking, and corrosion under jackets or washers. Every attempt to seal and rectify an abandoned well should be made as these could easily become the conduit of movement of pollutants up or down through the subsurface strata (Figure III-9).

Waste disposal wells or underground storage of oil or natural gas are another potential source of ground water contamination. In waste disposal wells, it is commonly a practice to inject waste through a deep injection well into a salt water aquifer. Pollution is possible in such wells from any potential leaks in the casing of the well in which waste can escape from the well and into an aquifer or by increasing the pressure within an aquifer by waste injection and forcing saline water or waste water into other aquifers.

POTENTIAL FOR GROUND WATER CONTAMINATION

Alluvium

In the alluvium of the Yellowstone-Tongue project area, the quality of the water is generally excellent. Potential for pollution or contamination is always great in alluvium since alluvium is always a surficial outcrop. This contamination potential can spread to streams and lakes located within the alluvial deposit. Contamination can result from surficial sources such as feed lots or chemical spills, from contaminated sources within the ground such as improperly constructed land fill sites or septic systems, or from poorly constructed wells with such faulty components as an improper seal at ground surface. In addition, alluvial ground water can be contaminated by polluted lakes and streams. In short, alluvial ground water can be contaminated by nearly every source of ground water contamination.

White River Group

In areas of saturated thickness to the south, the Arikaree formation can yield as much as several hundred gallons per minute. However, in the Yellowstone-Tongue project area, the White River is a resistant sandstone capping mesas and hills. Some water is available here but is generally not in significant amounts. Potential for pollution is not great in the study area because of the generally high outcrop location and the minimal lateral extent of the White River Group in the project area.

Wasatch Formation

The Wasatch formation is not considered to be a major aquifer although some high yields have been reported. Dissolved solids can range from about 500 to 2,000 mg/l but generally are between 500 to 1,500 ml/l. The water types are generally sodium bicarbonate and sodium sulfate. The major pollution potential is from coal mining.

Fort Union Formation

Shallow water within the Fort Union formation is generally hard and the hardness decreases with depth. Major constituents of the water can include sulfate, calcium, sodium bicarbonate, and magnesium. In general, the freshest water comes from the clinker beds which have 270 to about 1,300 milligrams per liter of total dissolved solids around Birney in the southwest part of the project area. Where coal beds are sufficiently fractured, they can be reliable aquifers for domestic and stock purposes. Dissolved solids in the coal beds range from about 1,000 to about 2,500 milligrams per liter. Principal constituents in the ground water from the coal beds are calcium, magnesium, and sulfate.

Pollution potential is greatest for possible coal mining activities. Reclamation efforts in coal-mined areas can result in pollution to ground water aquifers as overlying material would be replaced in the form of coarse rubble, making the leaching out of potential contaminants and minerals more likely. Ground water recharged by water

passing through such areas is likely to be more highly mineralized. Water levels in the wells surrounding the mine area will drop as dewatering procedures are undertaken in the coal mine itself. Aquifers overlying the coal will be removed with probable result of a lowering of the nearby water table. Possible increases in the acid content of water will be a result of solution of metallic sulfides resulting in sulfuric acid. Coal mines located in the alluvium as well as bedrock aquifers can result in possible contamination to surficial and confined aquifers. However, coal mines located in the bedrock alone will possibly limit the contamination to confined aquifers only. Mines penetrating formations in a recharge area will have a greater contamination potential for the ground water than mines located in a discharge area.

Hell Creek Formation

Quality of water from the Hell Creek formation ranges from excellent to poor and is generally a sodium bicarbonate type. The total dissolved solids ranges from about 700 to 2,000 milligrams per liter. Generally, the upper part of the Hell Creek formation is not considered to be a prominent aquifer. Pollution results from coal mining in the area as well as other modes of contamination listed in this section.

Fox Hills Sandstone

In southeastern Montana, the Fox Hills sandstone and the lower portion of the Hell Creek formation are

considered a single aquifer. This aquifer is generally adequate for domestic and stock supplies with the water a sodium bicarbonate type. Total dissolved solids in this formation can be as much as 1,500 milligrams per liter. The Fox Hills sandstone is a principal source of domestic, stock, and industrial water in much of southeastern Montana. The exception is near the Black Hills uplift and the Cedar Creek anticline.

Pierre Shale

In most of the Yellowstone-Tongue project area, the Pierre shale is not considered a source of ground water supplies. However, to the northwest, the Judith River formation and the Eagle sandstone provide moderate amounts of water. These formations, along with the Bearpaw shale, the Claggett formation, and the Telegraph Creek formation, grade into the Pierre shale in the eastern part of the project area. Water from the Judith River formation has much sodium chloride or sodium sulfate. Water from the Eagle sandstone ranges from fresh to slightly saline and is a sodium bicarbonate type. Yields in the northwest portion of the project area are generally small and, as these aquifers grade into the Pierre shale, become non-existent. Pollution potential in these aquifers is probably moderate and subject to general contamination such as is covered in another portion of this report.

Colorado Group

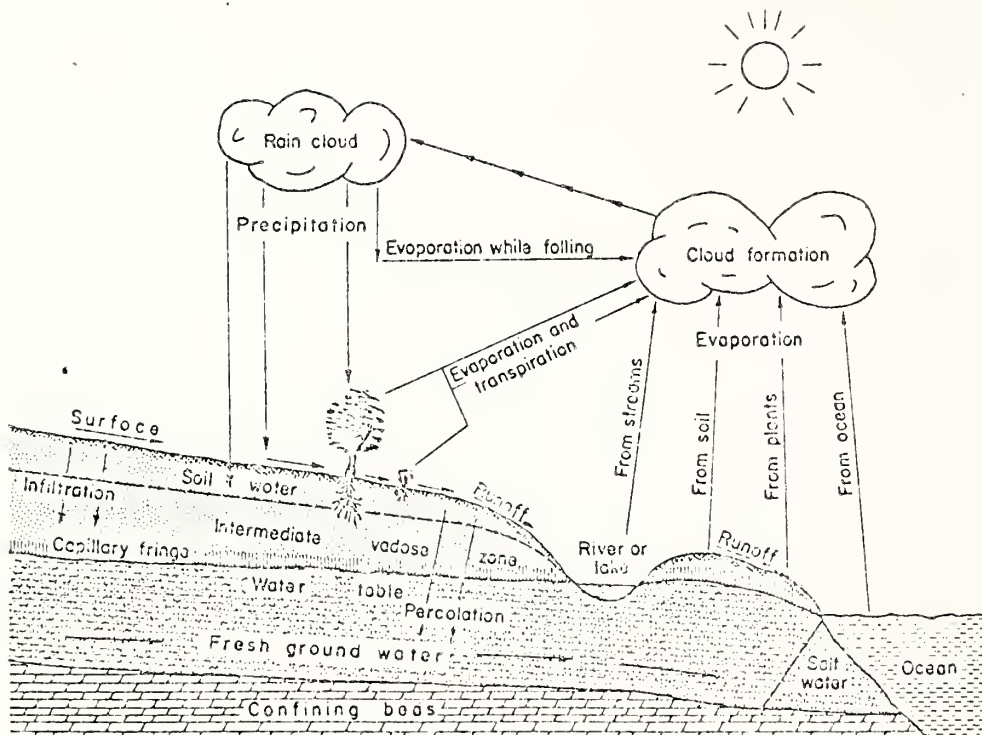
The Colorado group, consisting of the Niobrara formation, the Carlile shale, the Greenhorn formation, the Belle Fourche formation, the Mowry formation, and the Thermopolis shale are not considered aquifers.

Madison Limestone

Large yields of water have been obtained from the Madison group during oil field operations, and the water quality is good to poor. However, water wells pumped near Porcupine dome yielded moderately saline water. Water quality may improve at a distance from oil field operations. Ground water from the Madison group is possibly subject to contamination as a result of oil field activities. Such contamination can result from secondary and tertiary oil recovery, faulty well seals, and possible movements into other aquifers. Figures III-10 and 13 depict pertinent Madison geohydrologic factors.

Other Aquifers

In the Yellowstone-Tongue project area, generally the Madison is the lowermost formation considered an aquifer. Although water may be found in other aquifers underlying the Madison formation, generally the depth of drilling would be prohibitive to development of ground water in these formations.



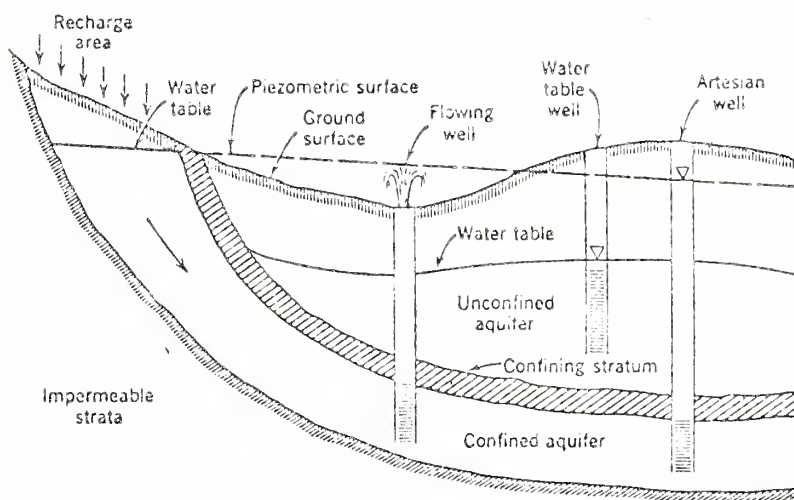
The Hydrologic Cycle

From Johnson, 1966

WILLARD OWENS
ASSOCIATES
INC



FIGURE III-1



Confined and Unconfined Aquifers

From Todd, 1959

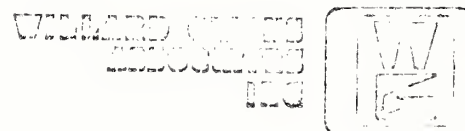
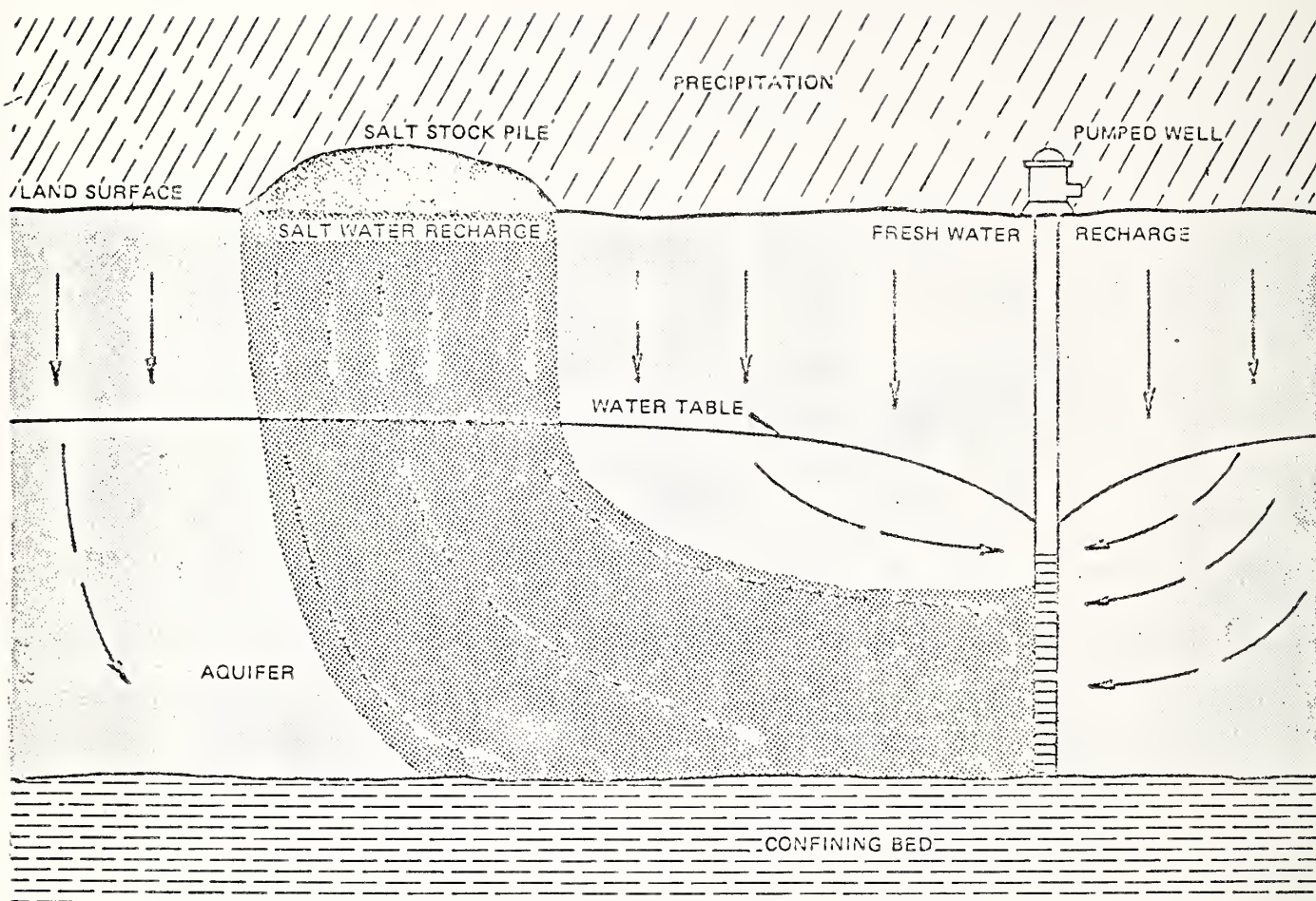


FIGURE III-2



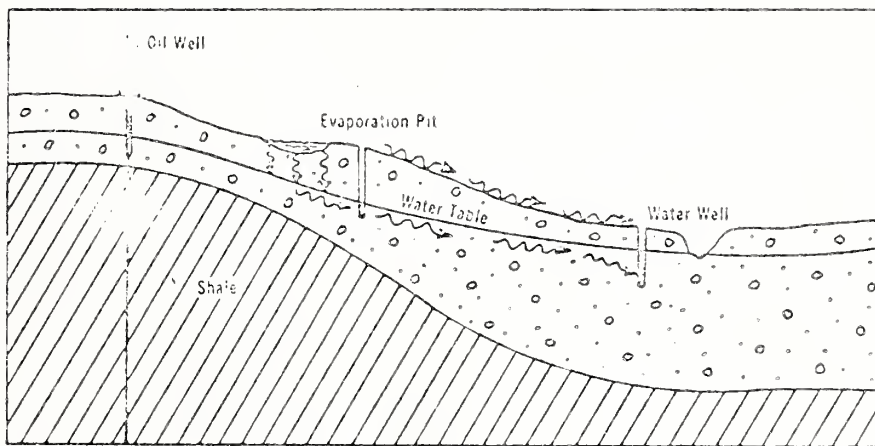
Ground Water Contamination by a Salt Stock Pile

After Deutsch, 1963

WILLARD OWENS
ENGINEERS
INC



FIGURE III-3



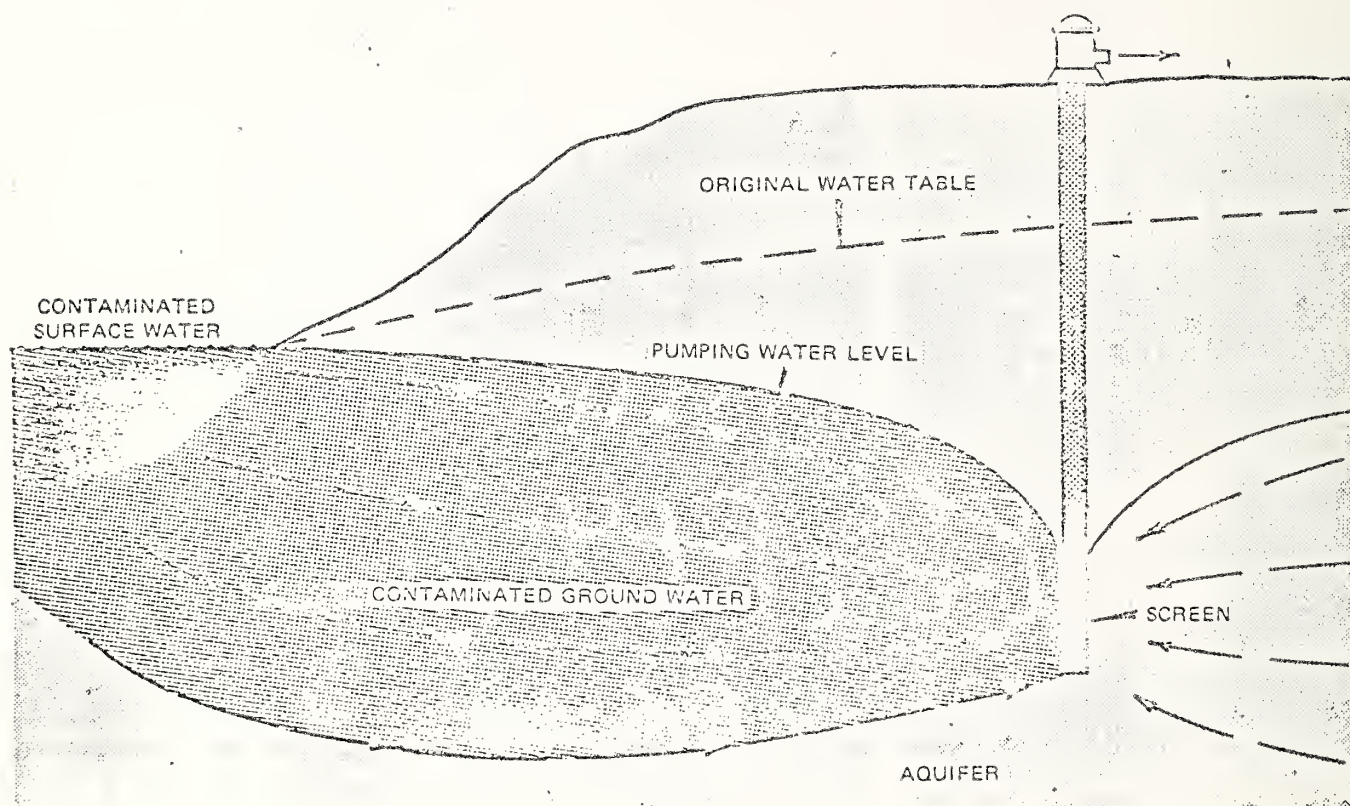
Ground Water Contamination from an Evaporation Pit

From Campbell and Lehr,
Water Well Technology

WILLARD CHERRY
ARCHITECT
INC.



FIGURE III-4



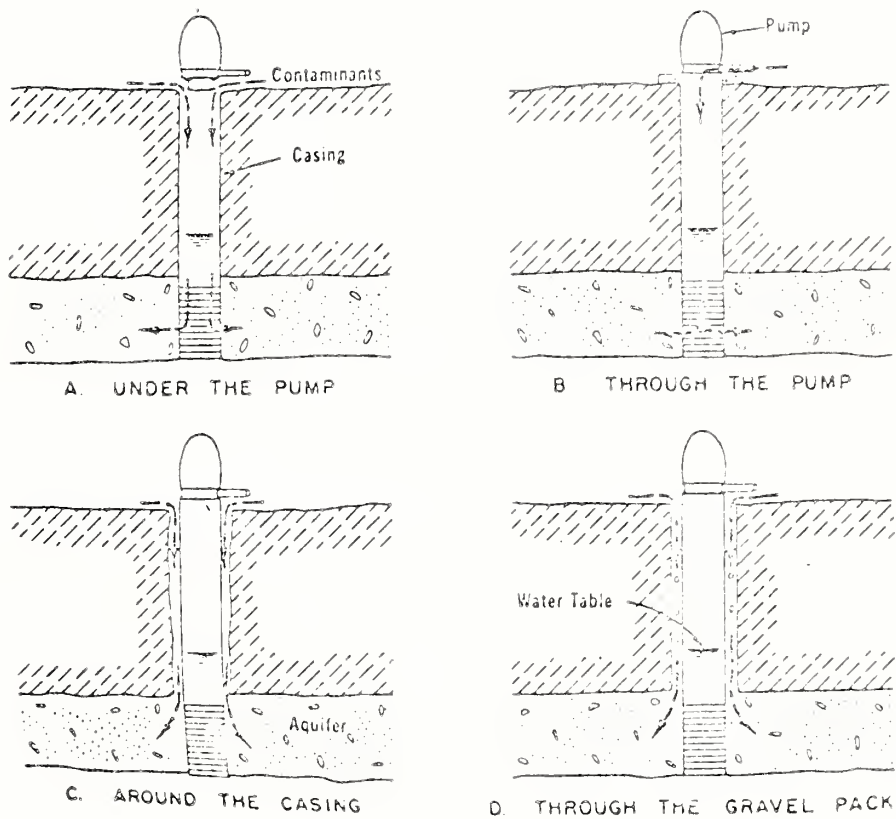
Ground Water Contamination from Polluted Surface Water

After Deutsch, 1963

WILLARD OWENS
ENGINEERS
INC



FIGURE III-5

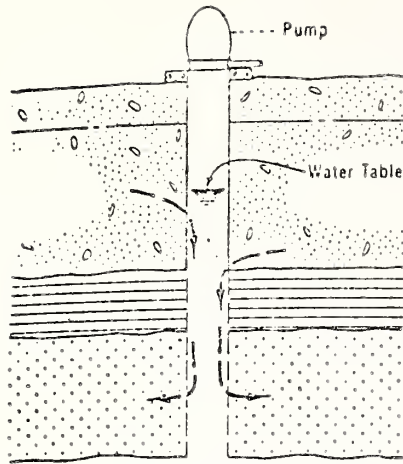


Ground Water Contamination from Ground Surface Through Well

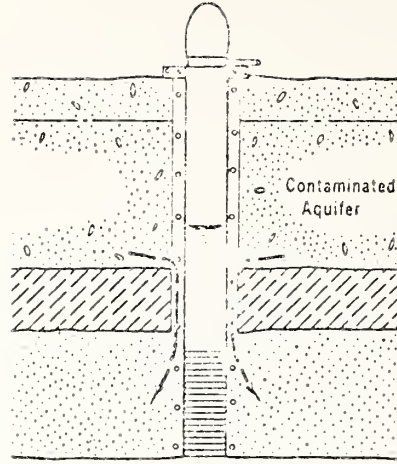
From Campbell and Lehr,
Water Well Technology

WILLARD OWENS
HYDROLOGICAL
INC



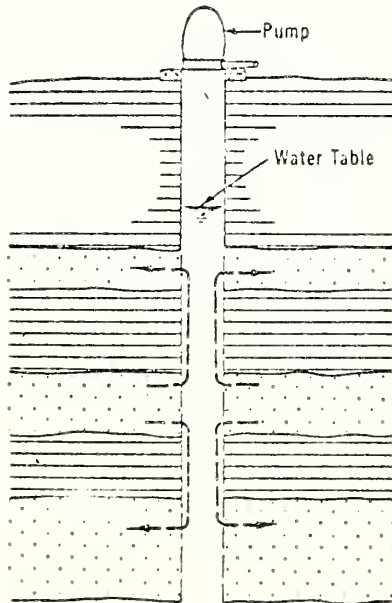


A. THROUGH THE CASING

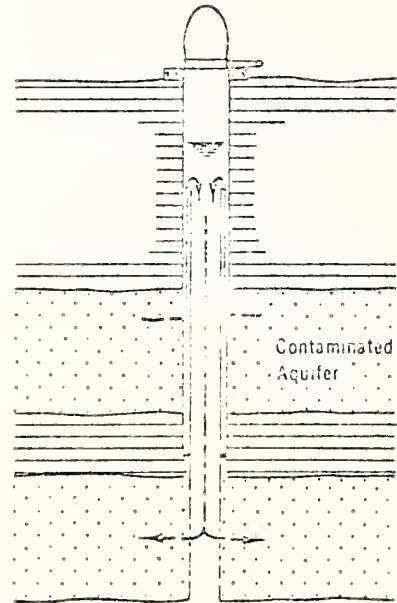


B. INTO THE GRAVEL PACK

Figure 6 300 Entrance of contaminants.



A. BY VERTICAL FLOW



B. BY VERTICAL FLOW BY-PASSING
A LINER

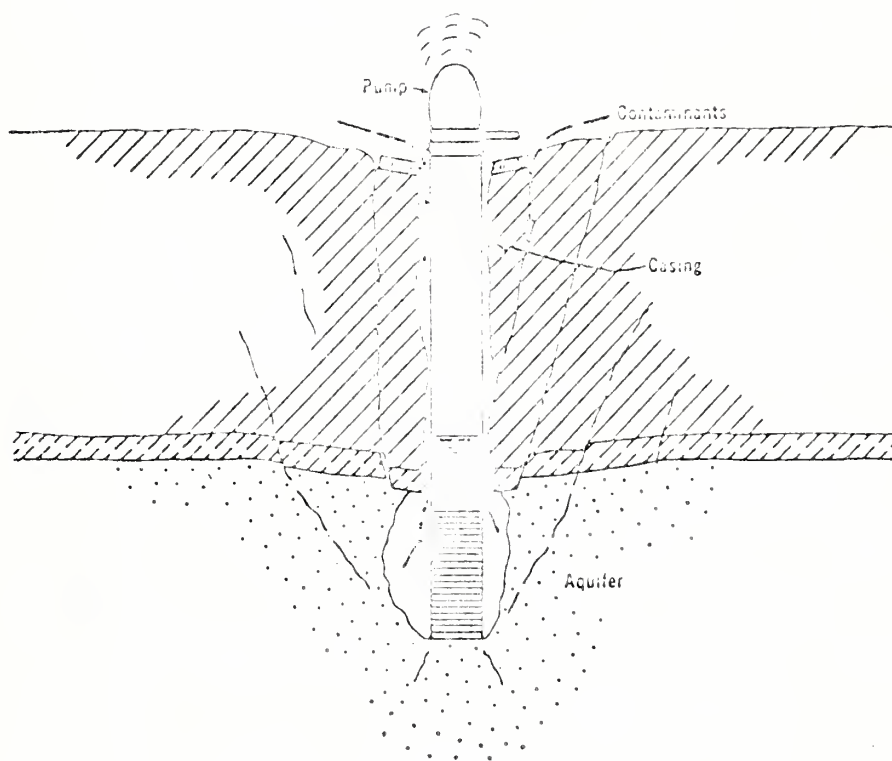
Ground Water Contamination Within a Well

WILLIAM OWENS
ENGINEERING
INC.



From Campbell and Lehr
Water Well Technology

FIGURE III-7



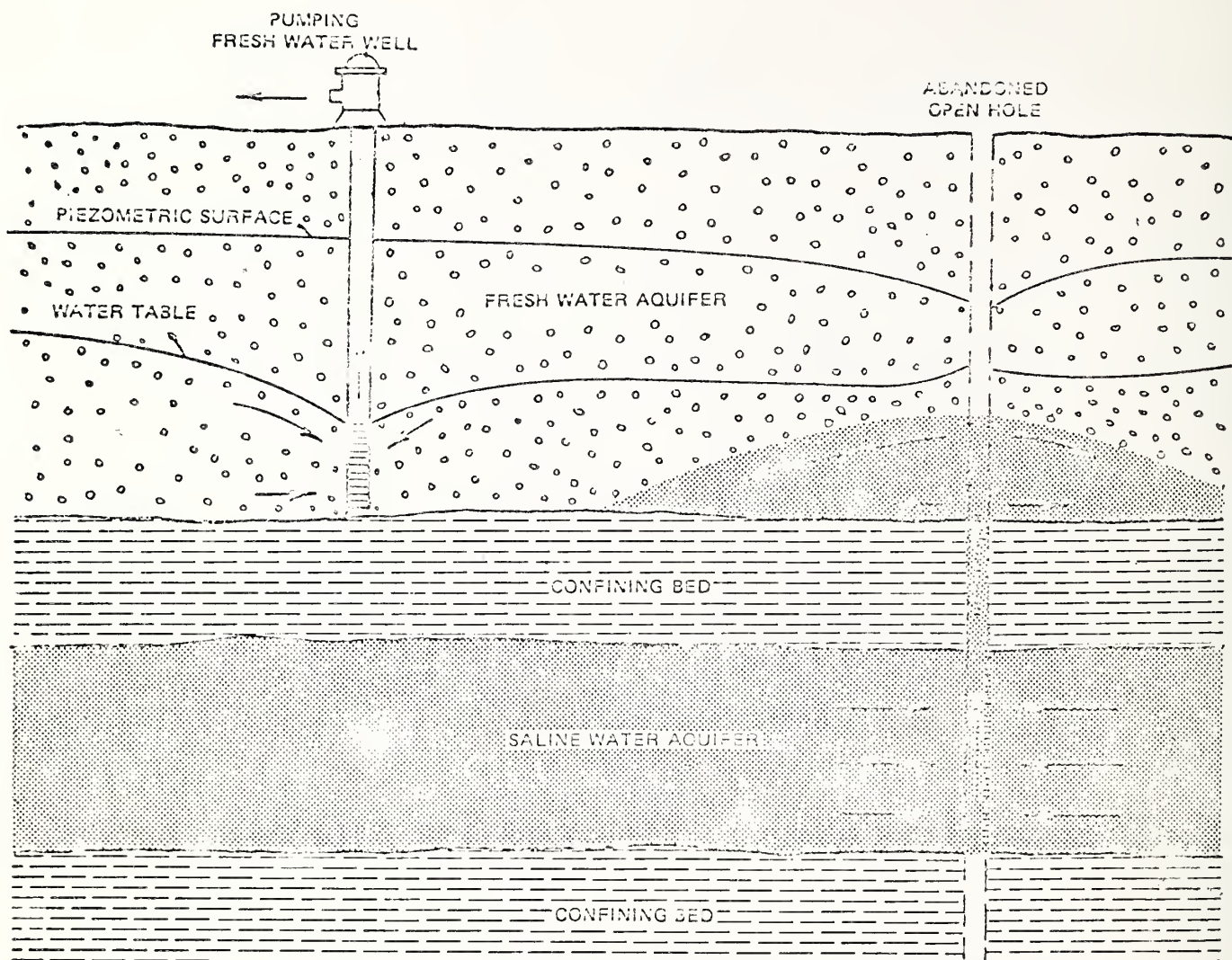
Subsidence of Well From Vibration and Sand Pumping

From Campbell and Lehr,
Water Well Technology

WILLARD OWENS
ASSOCIATES
INC



FIGURE III-8

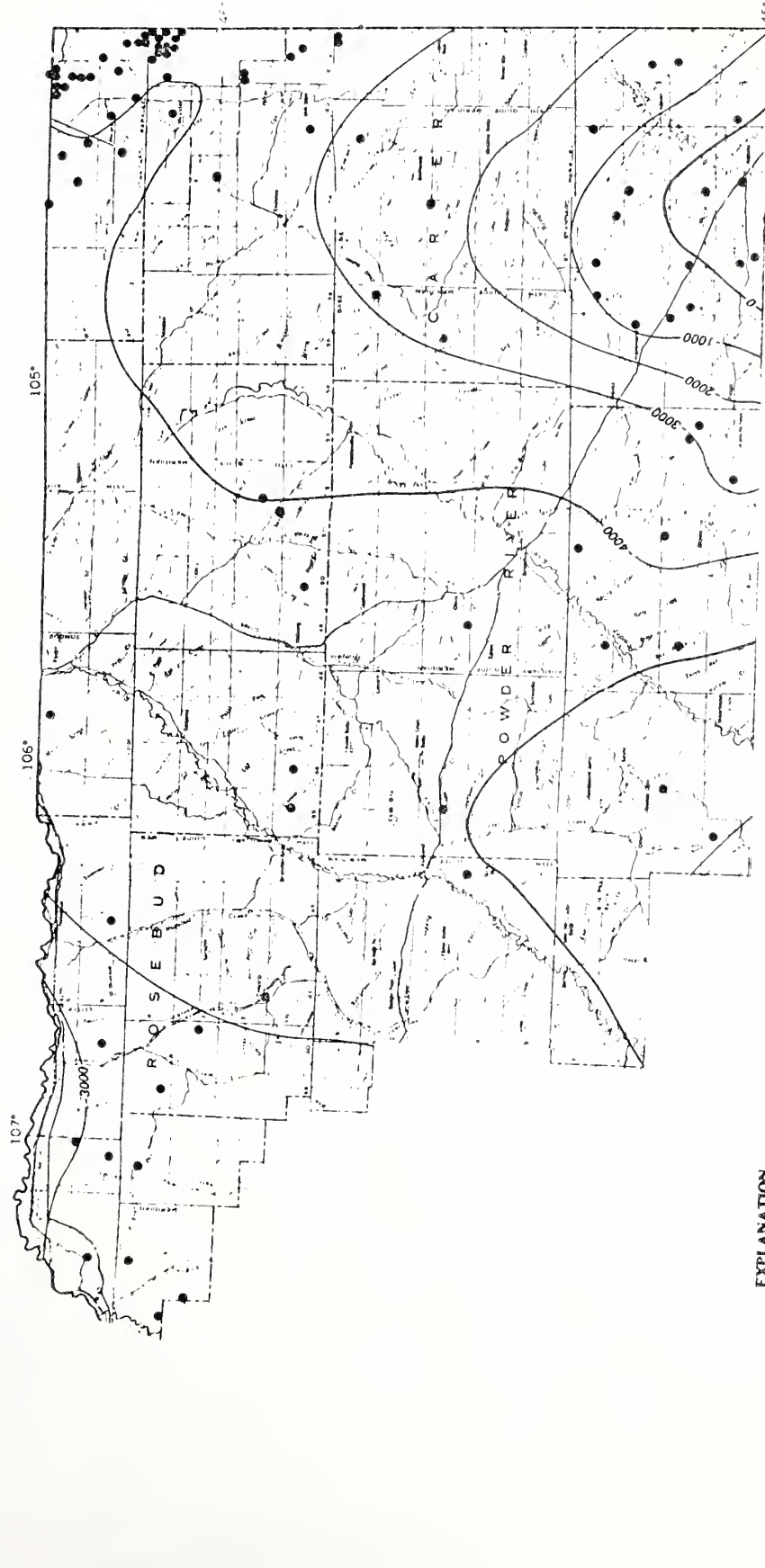


Ground Water Contamination from Abandoned Open Hole



FIGURE III-9

MAP SHOWING CONFIGURATION OF THE TOP OF THE MADISON GROUP



EXPLANATION

— 5000 — CONTOUR — Shows altitude of top of Madison Group. Contour interval 1,000 feet (300 metres). Datum is mean sea level

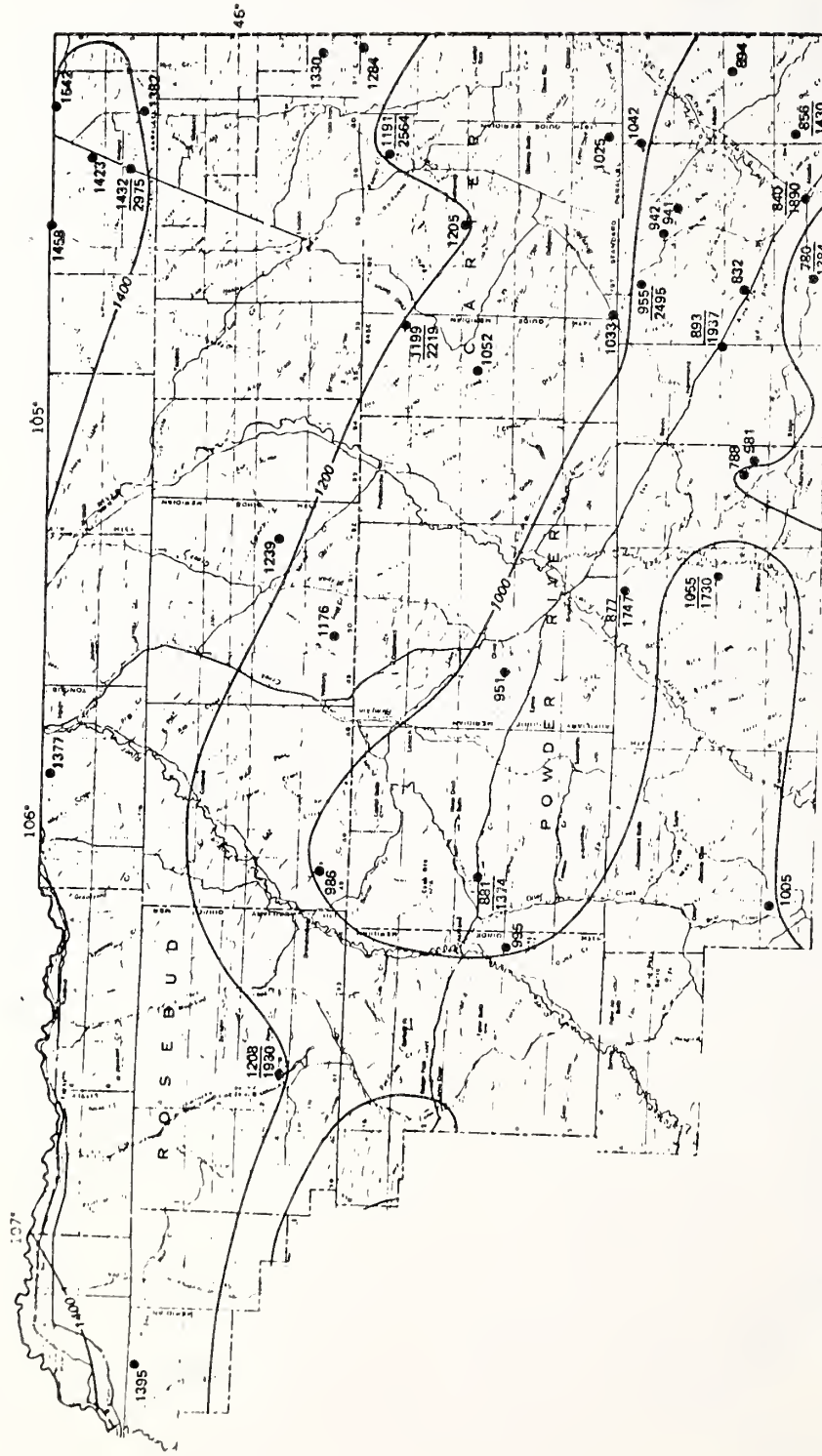
• DATA SITE

U FAULT — U, upthrown side; D, downthrown side

◻ AREA WHERE MADISON GROUP IS ABSENT

from Swenson et al., 1970

MAP SHOWING GENERALIZED THICKNESS OF THE MADISON GROUP WITH SUPPLEMENTAL DATA ON TOTAL THICKNESS OF THE CARBONATE-ROCK AQUIFER

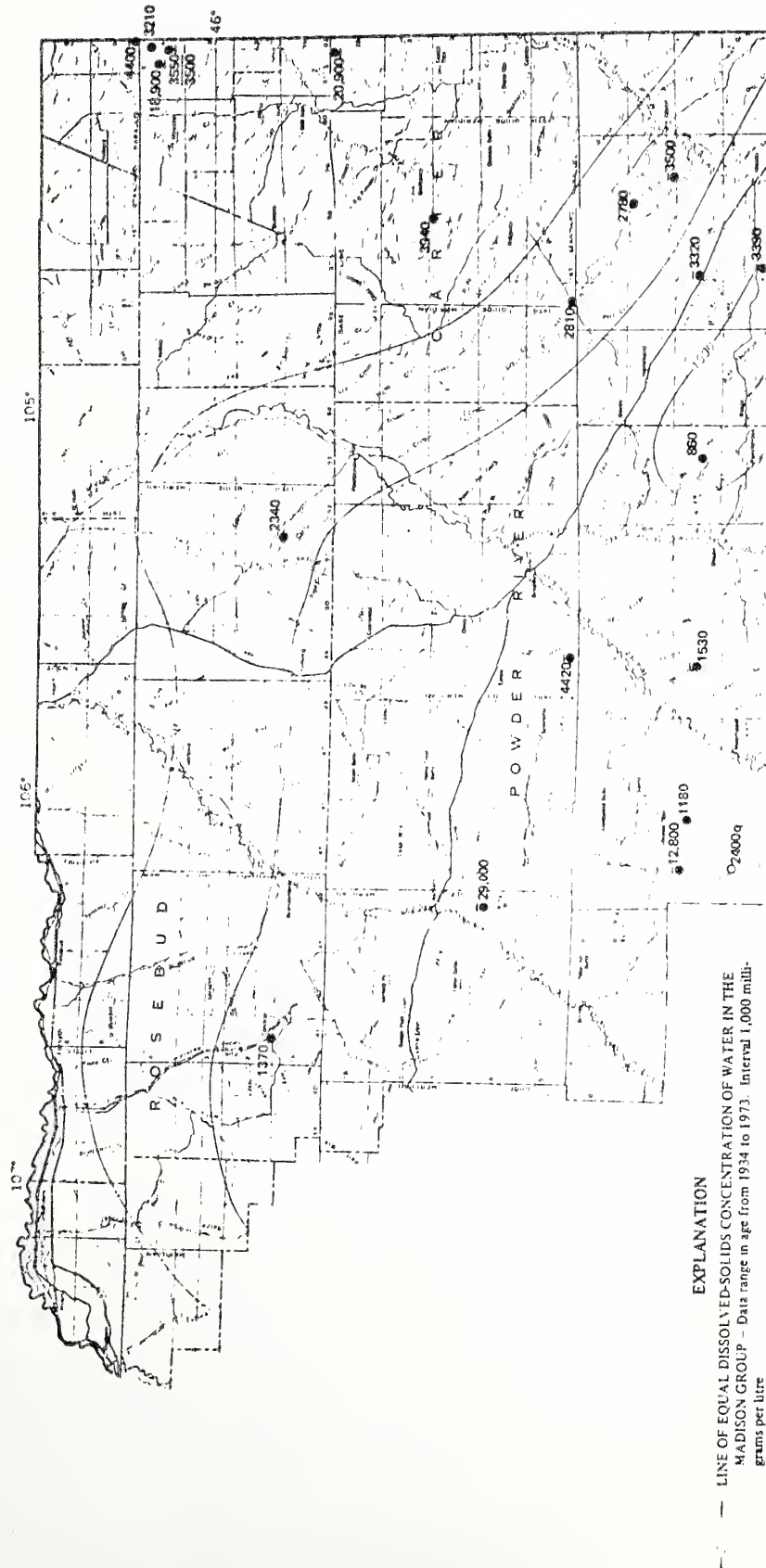


EXPLANATION

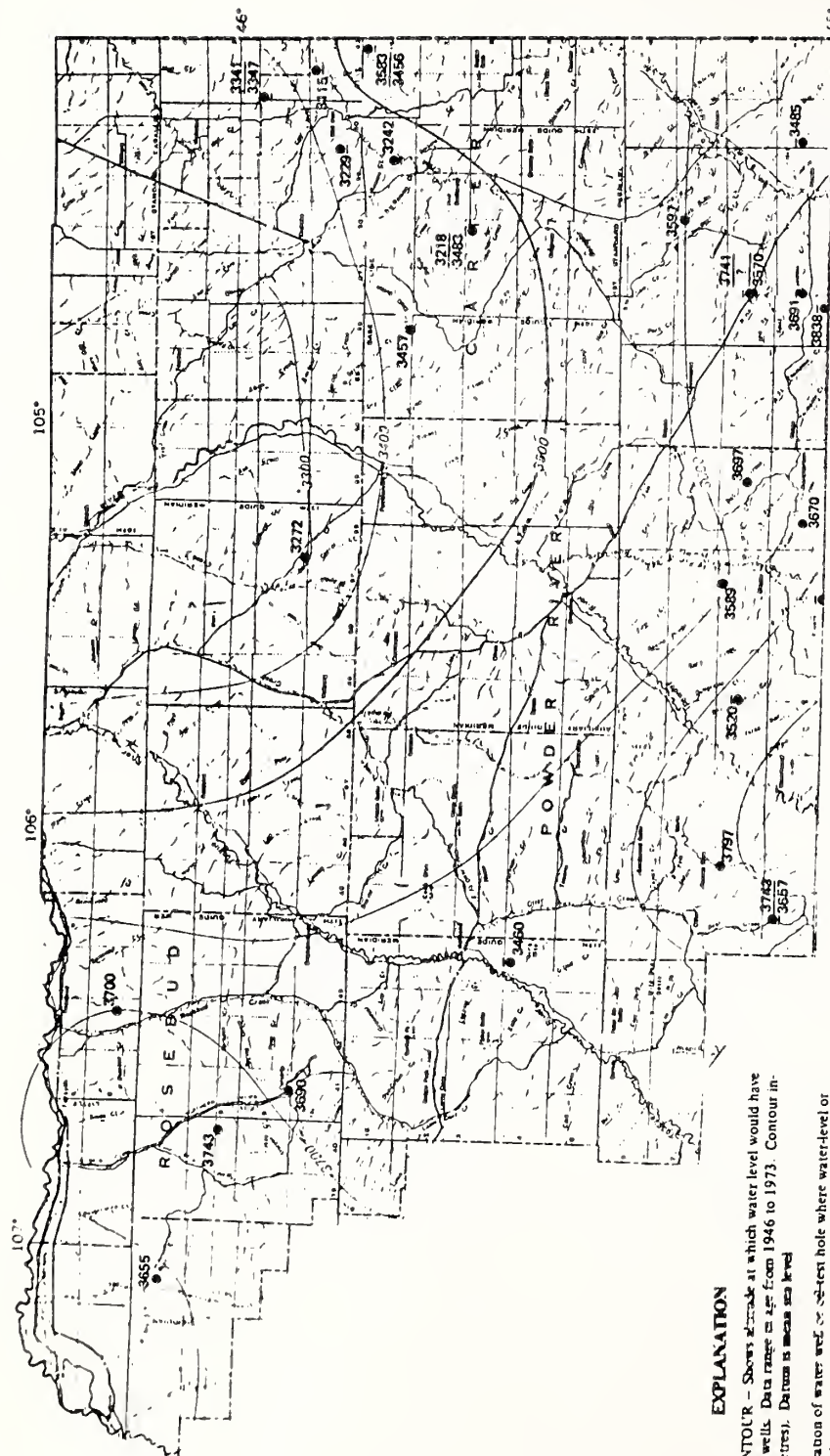
- 600 — LINE OF EQUAL THICKNESS OF MADISON GROUP - Dashed where approximately located. Interval 200 feet (60 metres)
- 310 DATA SITE - Shows location of water well, oil well, or test hole where thickness information has been collected for the Madison Group. Where two numbers are given, the lower number is the combined thickness of the Madison Group and the underlying carbonate rocks
- 784 Questionable data; not used to construct lines
- ◊ AREA WHERE MADISON GROUP IS ABSENT

From Swenson et. al., 1976

MAP SHOWING DISSOLVED-SOLIDS CONCENTRATION IN WATER FROM THE MADISON GROUP, WITH SUPPLEMENTAL DATA ON WATER FROM OVERLYING AND UNDERLYING ROCK UNITS



MAP SHOWING PRELIMINARY CONCEPT OF POTENTIOMETRIC SURFACE OF WATER IN THE MADISON GROUP, WITH SUPPLEMENTAL DATA FOR OVERLYING AND UNDERLYING ROCK UNITS



EXPLANATION

- POTENTIOMETRIC CONTOUR - Shows altitude at which water level would have stood in tightly cased wells. Data range in age from 1946 to 1973. Contour interval 100 feet (30 metres). Datum is mean sea level
- DATA SITE - Shows location of water well or test hole where water-level or pressure measurement has been made. Number indicates altitude of potentiometric surface, in feet, in the Madison Group. Supplemental data are also given at some sites for the rocks overlying the Madison (Tensleep Sandstone, Minnelusa or Amsden Formation) and for carbonate rocks underlying the Madison (Bighorn Dolomite or Red River Formation). Supplemental data were not used to construct contours. Supplemental data for the overlying rocks and for the underlying rocks are shown by the following symbols

- Rock units overlying the Madison. Where two numbers are given, the lower number is for the Madison
- Rock units underlying the Madison. Where two numbers are given, the upper number is for the Madison
- Upper number is for the overlying rock mass; middle number is for the Madison; and lower number is for the underlying rock mass
- AREA WHERE MADISON GROUP IS ABSENT

From Swenson et.al., 1976

TABLE III-1

DRINKING WATER STANDARDS OF THE U.S. PUBLIC HEALTH SERVICE

(Source: U.S. Public Health Service, 1962)

Substance	Recommended limits of concentrations, in mg/l	Mandatory limits of concentrations, in mg/l
Alkyl benzene sulfonate (ABS)	0.5	----
Arsenic (As)	0.01	0.05
Barium (Ba)	----	1.0
Cadmium (Cd)	----	0.01
Carbon chloroform extract (CCE)	0.2	----
Chloride (Cl)	250.0	----
Chromium (hexavalent) (Cr^{+6})	----	0.05
Copper (Cu)	1.0	----
Cyanide (CN)	0.01	0.2
Iron (Fe)	0.3	----
Lead (Pb)	----	0.05
Manganese (Mn)	0.05	----
Nitrate (NO_3)	45.0	----
Phenols	0.001	----
Selenium (Se)	----	0.01
Silver (Ag)	----	0.05
Sulfate (SO_4)	250.0	----
Total Dissolved Solids (TDS)	500.0	----
Zinc (Zn)	5.0	----

Source: Ground Water Contamination -
An Explanation of its
Causes and Effects by
Geology and Miller, Inc., 1962

TABLE III-2
RECOMMENDED CONTROL LIMITS ON FLUORIDE

<u>Annual Average of Maximum Daily Air Temperatures^a</u>	<u>Recommended Control Limits (Fluoride Concentrations in mg/l</u>		
	<u>Lower</u>	<u>Optimum</u>	<u>Upper</u>
50.0-53.7 -----	0.9	1.2	1.7
53.8-58.3 -----	0.8	1.1	1.5
58.4-63.8 -----	0.8	1.0	1.3
63.9-70.6 -----	0.7	0.9	1.2
70.7-79.2 -----	0.7	0.8	1.0
79.3-90.5 -----	0.6	0.7	0.8

^aBased on temperature data obtained for a minimum of five years.

SECTION IV

GROUND WATER CONTAMINATION DUE TO URANIUM EXPLORATION
SOLUTION MINING

IV. GROUND WATER CONTAMINATION DUE TO URANIUM EXPLORATION AND SOLUTION MINING

In this portion of our report we will examine the characteristic geology of uranium deposits, its potential in southeastern Montana, exploration techniques, alternative mining methods including solution mining and regulation of the solution mining industry.

Two major mining methods, open pit and underground, have been used in the past to mine uranium. A new method, solution mining, has been developed and shows promise as an economical method of mining uranium. Because solution mining is relatively new and generally untested, the impacts of this method on the environment are not totally documented. The primary objectives of this report are to explain solution mining, evaluate the advantaged and disadvantages of this method, review regulations applicable to solution mining in Montana, and provide recommendations for regulating this method of mining.

GEOLOGY OF DEPOSITS

In the western portion of the United States there are basically three different types of uranium ore bodies encountered: tabular, vein and roll-front. Of these, only roll-front deposits are of significant importance in southeastern Montana; however, we will briefly discuss all three methods.

Typically in the western part of Colorado and Utah, uranium deposits are located in sandstone lenses and shales in a tabular fashion, and typically called tabular ore bodies. In the Precambrian rocks of the Front Range of the Rocky Mountains of Colorado and in areas of the northern Rockies in Montana, uranium occurs in veins which are fractures filled with uranium bearing minerals such as pitchblende. Vein deposits, generally, are small localized deposits commonly of moderately high grade.

In the Powder River Basin of Wyoming and in southwest Texas, uranium typically occurs in what is known to geologists as a roll-front. Roll-front deposits and uranium in lignite are the most probable types to occur in the region of southeast Montana and are, therefore, of most interest. Roll-front deposits have been extensively developed in the Powder River Basin in Wyoming. This development has led to extensive study of the

deposits, and a model has been developed to explain the origin and deposition of the uranium.

Generally it is believed that the uranium was originally deposited in beds of volcanic ash. Much later as a result of hydrolysis, the uranium, perhaps with vanadium, selenium, and molybdenum from the volcanic ash, was transmitted by an oxidizing slightly alkaline ground water through ancient buried stream channels of medium to coarse-grained alluvial arkosic sandstones. As the uranium-pregnant ground water moved through the sandstone alteration to the sandstone occurred. The feldspar grains altered to kaolinite clay; the iron minerals altered to hematite and limonite. Figure IV-1 shows the zones of rock alteration.

Although the mechanism causing the deposition of uranium is not totally understood, it is apparently related to a change in rock permeability, rock porosity, and the presence of reductants. At the point of deposition, which is a reducing-oxidizing interface, the uranium is precipitated from the solution as a fine coating on sandstone grains. In map view, the reducing-oxidizing interface, commonly called a roll-front, exists in a horseshoe shape with the tails pointing in the direction of the original source of uranium. In a cross section the roll-front appears horseshoe or C-shaped again with the tails pointing toward the original source. Quite commonly this roll-

front is not perfectly C-shaped and is complicated by local changes in lithology and different periods of uranium deposition. Generally, the roll-front thickens toward the front and the uranium is most highly concentrated in the frontal area. Figure IV-2 shows the zoning of the deposited ions.

It is generally thought that the uranium pregnant solutions can migrate for a considerable distance prior to final deposition. It is also thought that through changes in chemical quality of the ground water and changes in permeability, the uranium can be redissolved into solution and migrate to another deposition point. Consequently, the uranium may be deposited in a very complex ore body due to several episodes of migration.

The most common uranium minerals found in a roll-front deposit are uraninite, UO_2 to U_3O_8 , and coffinite. Near surface weathering alters these minerals to tyuyamunite, $\text{Ca}(\text{UO}_2)_2(\text{VO}_4)_2 \cdot n\text{H}_2\text{O}$, carnotite, $\text{K}_2(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 3\text{H}_2\text{O}$ and uranophane, a calcium uranium silicate.

EXPLORATION TECHNIQUES

Although each company searching for uranium has its own procedures and methods of exploration, these exploration procedures can be generalized into: 1) regional evaluation, 2) local target evaluation, and 3) target development.

Regional Evaluation

The regional target evaluation procedures utilizes many techniques, such as review of existing reports of occurrences of uranium in an area, rumors, radiometric aerial surveys of large areas, stream sediment sampling to locate anomalous concentrations of uranium, geologic mapping and modeling and reconnaissance drilling. Occasionally, prospecting is done by small operators who drill a small number of test holes in hopes of randomly locating uranium mineralization.

Local Target Evaluation

Generally, the well organized staff of explorationists will investigate a rather large area such as the Powder River Basin and eliminate those areas that geologically are not favorable. They then utilize past mining industry exploration data to eliminate additional areas until fairly small local targets are selected. During the evaluation of these local targets, widely spaced drilling of test holes is often conducted.

The test holes vary in grid distances typically on the order of one mile apart. These holes are commonly drilled through the entire stratigraphic section that is thought to be uranium bearing. Normally, a 4 3/4 inch diameter hole is drilled with rotary drilling equipment. Normal depths range from approximately 500 to 1000 feet, although drilling has been exceeded by 2,000 feet.

Generally, the boreholes are geophysically logged to measure gross gamma radiation, formation resistivity, and spontaneous potential developed between contacts separating geologic formations. This information coupled with collected samples of drill cuttings is used to correlate between drill holes and develop an interpretation of the subsurface geology. Areas of anomalous characteristics are further evaluated with more closely spaced drill holes to core the zone of interest to recover undisturbed samples of the formation for closer geologic and chemical laboratory analysis.

Target Development

If uranium is found to exist in concentrations approaching economically mineable grades extensive development drilling is undertaken on closely spaced holes to define the roll-front, ore thickness and location. These holes may be spaced at the surface on 20 foot centers. Figure IV-3 shows hypothetical drilling

program. In the past closely spaced drilling has been required to evaluate the ore grade, total reserves, and depth of burial. This information, coupled with data on site accessibility, market conditions, topographic conditions and ground water conditions, is utilized to develop an economic plan for mining the deposit. Once a mining method is selected and mining begins, continued drilling occurs ahead of the mining to verify and project ore trends.

DRILLING AND GROUND WATER CONTAMINATION

Drilling Techniques

In most cases the exploration drilling is conducted at fast rates on mobile drilling rigs that are capable of up to 40,000 to 50,000 feet of drilling per rig per month. Drilling is normally done by one of two common methods. The most common is mud rotary method, which uses a bentonite-water fluid (mud) circulating downward through the drill pipe and upward through the annulus between the pipe and the drill hole. The fluid provides cooling to the drill bit and a method of floating the cuttings out of the drill hole. The second method utilizes compressed air to produce the same results.

The advantage of a bentonite mud system is that it allows drilling to proceed in areas of water-saturated or unconsolidated rocks. The drilling mud tends to infiltrate into water bearing horizons, clogging the pore

space in the vicinity of the drill hole and reducing the amount of fluid lost to the permeable formation. The mud weight establishes an equilibrium between formation and borehole pressures to prevent the drill hole from caving during the drilling operation. The advantages of drilling with compressed air are the speed at which drilling can proceed and higher efficiency of cuttings removal, both of which reduce cost.

Potential Ground Water Contamination

Exploration drilling can indirectly cause ground water problems. Sterilization is generally not done nor are the holes commonly plugged to prevent interconnection between different water-saturated sandstone layers which may contain water of different qualities and different natural hydrostatic pressures. Generally, it is this interconnection rather than direct introduction of contaminants during drilling that is a significant problem. The interconnection between aquifers allows water to flow from the zone of high pressure to low pressure, thereby either draining the high pressure zone or reducing the pressure head and mixing waters of two different chemical qualities. If enough drill holes are completed in this manner in a given area the resulting pressure drop could dry up stock wells or produce detrimental changes in chemical water quality. Either of these problems adversely

affects ranchers or others living in the vicinity of exploration programs.

Attempted Remedial Measures

The mining industry commonly considers it uneconomical to prevent this cross contamination by installing casing and grout to separate aquifers. In Montana, Wyoming and other states it is common to fill the drill hole with heavy bentonite drilling fluid to prevent the cross contamination; drillers also place a cement plug at the ground surface to prevent contaminants and pollutants from entering the borehole following drilling completion. The success of this method has not been comprehensively studied, but it has become standard practice and is assumed to be satisfactory. This method is fairly inexpensive and exploration companies have been willing to expend the extra money to satisfy state requirements in this way.

Our experience has shown that in numerous areas of Colorado and Wyoming where plugging with bentonite and a cement cap was reportedly done, it has not been done. Apparently, in some areas where bentonite sealing has been done the bentonite fluid was not prepared properly.

In some areas, typically in Montana and Wyoming where the population density is so low, the interconnection of aquifers has not been considered a problem. In some cases interconnection has not been detected because the use of the aquifers as water supplies has been slight. We assume that in some cases the interconnected waters are similar in chemical quality or pressure so that the interconnection has not become a problem under natural pressures. In Texas and in eastern Colorado where population density is much higher, very obvious changes in water quality and formation pressures have been reported. Figure IV-4 is a generalized map of the Yellowstone-Tongue APO showing the areas of recent uranium exploration activity. Table IV-1 is a summary of exploration permits in the Yellowstone-Tongue APO.

MINING TECHNIQUES

Uranium has been historically mined by one or two major techniques. These are open pit surface mining, and underground mining.

Open Pit Mining

Open pit mining is commonly considered the more economical when comparing the cost of mining to the return upon sale of the product. Open pit mining is commonly done in areas where the uranium ore is near the surface. This method allows low ore grades to be economically mined. The amount of recoverable ore is greater using open pit mining since no support blocks have to be left as must be done in underground mining.

The limitations of open pit mining are the thickness of the overburden between the surface and uranium ore, the difficulty of mining the overburden, the amount of water-saturated material to be dewatered to reach the ore, and the surface restoration requirements of the state and federal authorities.

Underground Mining

Underground mining usually entails shafts, tunnels, and adits to reach the uranium ore body. It is usually used to selectively mine only the highest grade ore due to the high cost of these underground workings. This method is utilized where high grade uranium deposits are at depths too great for open pit mining.

Sometimes underground mining is done because regulations limit surface mining. Problems associated with the underground method involve the following: high cost per ton of ore mined, ventilating underground workings to reduce hazard of radon and other gases, dewatering shafts and tunnels, inhalation of particulates by personnel, continual exposure of personnel to high noise level, and the possibility of surface settlement due to underground workings.

Solution Mining

During the last decade solution mining has been developed to mine uranium. This method utilizes chemicals injected into the ore zone to leach uranium and return it into solution. The uranium pregnant solution is then pumped from the ore body to the surface where the uranium component is concentrated. The advantages of this method are that it minimizes surface damage, is not depth dependent, allows low grade deposits to be mined, does not require as high an investment in capital and equipment, and does not have the ventilation, radon or noise problems.

The problems associated with solution mining include the possibility of the chemical solutions escaping from the control of the solution mining operator, the possibility that unanticipated chemical reactions may

occur and uncontrolled leakage of chemicals from one aquifer to another. Improper well completion, and abandoned or faulty well casing in the solution mining field may cause pollution of other aquifers.

SOLUTION MINING METHOD

Solution mining of uranium is the in situ leaching of uranium and transporting it to the surface where it is separated from the leach solution and concentrated. The process description is shown diagrammatically on Figure IV-5. For solution mining to be successful the ore zones must be porous and permeable enough to serve as conduits for the migration of the uranium pregnant solutions. The porosity and permeability can not be so high as to cause too rapid migration, nor can the natural ground water velocity be so high as to cause escape of the injection fluids beyond the well field. Generally neither extreme condition exists.

Uranium Leaching Process

The leaching process includes drilling a series of wells into the ore body. Approximately half of these are injection wells and the other half are recovery wells. The wells can be arranged in different geometric patterns to derive the best recovery of solutions. Chemicals are injected into the injection wells either under pressure or by gravity feed to leach the uranium in place, allow it to become part of the ground water solution and migrate it to the recovery wells where it is pumped to the surface. The types of chemicals injected are dependent upon the preference of the mining company and the in-place geochemistry.

Westinghouse Corporation, currently considered the leader in the solution mining industry, utilizes a system injecting ammonium bicarbonate as a lixiviant and uses hydrogen peroxide as an oxidant. The concentrations used are generally weak. They are considered proprietary by the mining company, so their exact compositions have not been revealed.

The injection pressure and the pumping rates from the recovery wells are designed to establish equilibrium in the aquifer to allow the uranium solution and the injected chemicals to flow to the recovery wells with, theoretically, no escape of fluids. At the surface, the uranium-pregnant solution is run through an ionic exchange column to strip the uranium from the original injection solutions. The injection solutions are then reconstituted and reinjected into wells. This is shown on Figure IV-6. Once the uranium has been extracted it is precipitated as uranium slurry and then dried to form what is known as yellow-cake. The injection solutions are selected to minimize concentrations of other dissolvable ions to reduce the problem of disposing of these ions at the surface or the risk of ions escaping from the well field. A typical well field is shown on Figure IV-7.

Geochemistry and Hydrogeology

Prior to solution mining of an ore body most companies study the feasibility of solution mining and the geochemistry involved at the particular site. The hydrostatic pressures, the flow directions, velocities of migrating ground water, and porosity and permeability of each water saturated zone are all studied to determine the effects of injection and pumping on the hydrogeologic system. This information aids in selecting well location and geometry and design parameter of the wells. These studies are important to minimize the escape of ion solutions as well as to maximize the recovery of the uranium pregnant solution. The hydrogeologic information is determined from test holes completed as wells on which aquifer pumping tests are conducted and evaluated, from laboratory analysis of cores of the drill holes and from analysis of piezometric levels of all of the aquifers. Chemical analyses of the natural ground water and of the constituents of the rocks are evaluated to determine the concentrations of chemicals needed to dissolve the uranium mineral coating on the sand grains and also to evaluate the other chemical reactions which might result from the injection of the chemicals.

The ions expected to be mobilized utilizing the ammonium bicarbonate and hydrogen peroxide method in

order of decreasing concentration are calcium V_2O_5 , SiO_2 , aluminum, magnesium and molybdenum.

Uranium is only one element of a number of elements in the radioactive decay series. It is, therefore, possible that following complete removal of the uranium from the ore body a number of radioactive materials may remain. These are largely radon, radium 226, decay products of uranium, thorium, and potassium. However, the general belief is that solution mining does not serve to further concentrate these ions and generally does not dissolve a great number of the radioactive materials. They are generally left in place. It is possible, however, that some of these daughter products are dissolved and either carried to the surface or left in the aquifer as a result of the solution mining process.

Restoration of Aquifer

After completion of the solution mining, the aquifer is restored to a condition somewhat equivalent to that before mining by injecting chemical solutions into the aquifer to reverse or balance the chemical reactions caused by the initial injection. During the restoration stage chemical solutions are injected and recovered in a continuous cycle to replace the ions extracted or precipitate those ions mobilized. The chemical solutions utilized during restoration may result in mobilization of other ions, which may or may not remain

in solution upon completion of the restoration process. The nature of the chemicals injected and the amount of restoration necessary generally is dependent upon the original water quality.

Frequently the ground water quality associated with uranium deposits is such that it is not potable by humans or livestock prior to mining. Therefore, it is generally thought unnecessary to attempt to make this water potable following solution mining.

If, however, the uranium deposit occurs in an aquifer of potable water that is or may be utilized as a water supply the degree of restoration is generally greater in an attempt to return the water quality to a potable nature. Following restoration, wells are usually cement-grouted bottom to surface to prevent contamination or migration of fluids between aquifers.

Abandonment and Monitoring

During the initial well installation, monitor wells would be installed around the perimeter of the facility to monitor the possible escape of the fluids. Generally, it is wise to complete monitoring wells in both the overlying and underlying aquifers in the area to detect any cross contamination of aquifers.

A problem which may be of concern is contamination of aquifers due to leakage through old abandoned drill holes. Quite commonly an area selected for mining has

been extensively drilled by both the current operator and previous explorers. Commonly the holes have been abandoned to seal themselves or they have been filled with bentonite drilling fluid to serve as a barrier to prevent migration of ground water from a zone of high pressure to one of low pressure. It has been our experience that these holes do not effectively seal and while leakage may not be evident at the surface cross contamination of leaching fluid may occur during or after solution mining. It is difficult during the solution mining to know whether leakage is occurring if there is no surface evidence nor monitoring wells to detect changes in hydrostatic pressure or changes in chemical content of water.

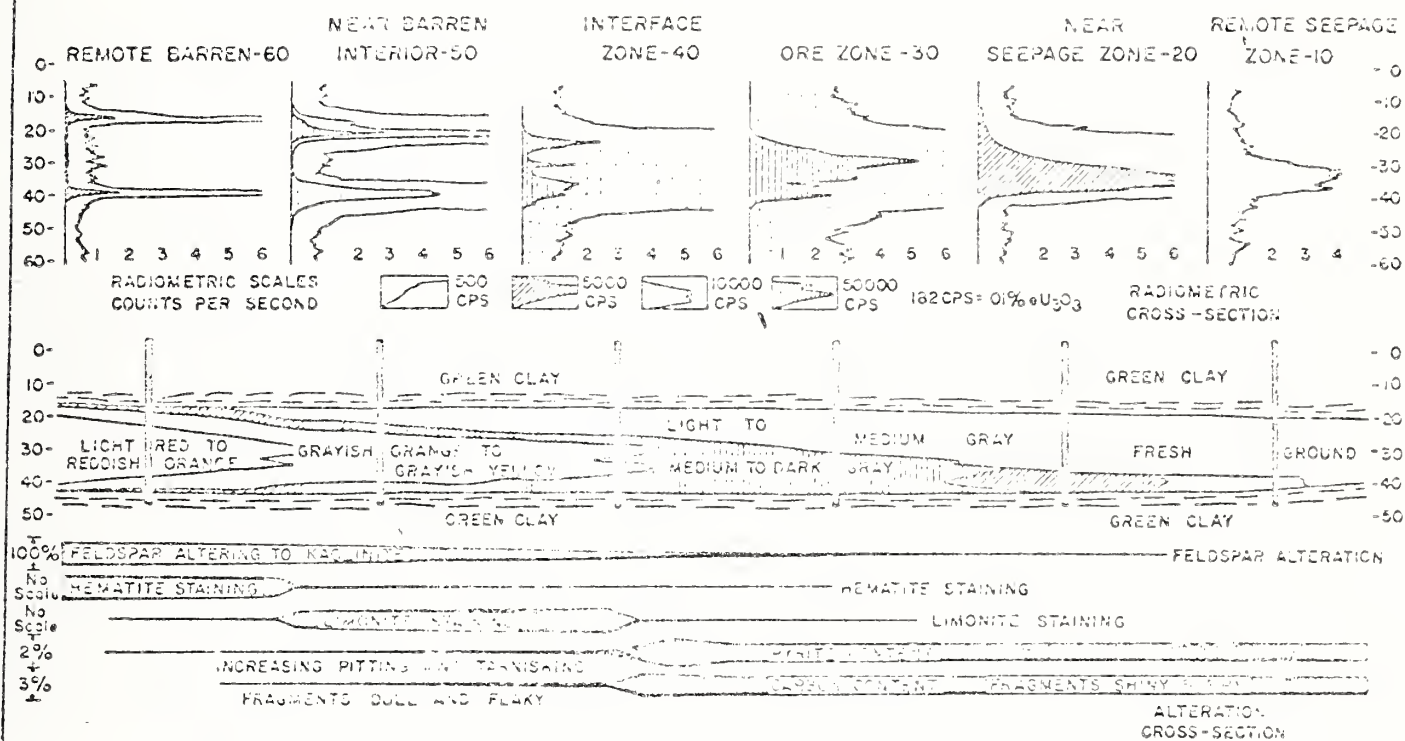
Another cause of cross contamination of aquifers is natural leakage through the confining aquicludes (strata of low permeability). In most circumstances the barriers are sufficiently impermeable to restrict any cross contamination but they may not be in other cases. It is important that the integrity of the confining shales between aquifers be examined to determine the potential of cross contamination.

Feasibility of Solution Mining

As in all uranium mining methods there is a certain amount of risk due to the radioactive nature of the product. Fortunately the concentrated uranium

that is at the mine site as yellow-cake is not generally highly radioactive and can be safely handled. There are numerous regulations to control disposal and transportation of this material; these are followed by companies in the industry. Enforcement of reasonable regulations, however, is necessary. Solution mining operators must also consider the risk hazard due to surface spills, flooding, or leakage of the chemicals at the concentrating facility. These chemicals can be carried in precipitation, runoff, or absorbed into the soil where they might pose a hazard in the future. However, with care, these spills and leaks can be prevented or at least minimized.

In summary, solution mining is technically feasible. It can be done with minimal risk to ground water supplies, but prior careful study of the local hydrogeology must be conducted, and the leaching program must be designed to prevent loss of solutions. It is ultimately most important that the company conducting the leaching operation understands the technique they are using, the potential hazards, the need for adequate monitoring before, during, and after the solution mining to ensure that the mining can be done safely without pollution.



GENERAL ROCK DESCRIPTION

ARKOSIC SAND - COMPACTED BUT NOT CEMENTED
 MEDIUM TO COARSE GRAIN
 FAIR SORTING
 SUB-ANGULAR TO SUB-ROUNDED SHAPES
 QUARTZ > 80% FELDSPAR < 15%
 CARBON FRAGMENTS < 5% PYRITE < 1%
 BLACK AND GREEN ACCESSORY MINERALS < 1%

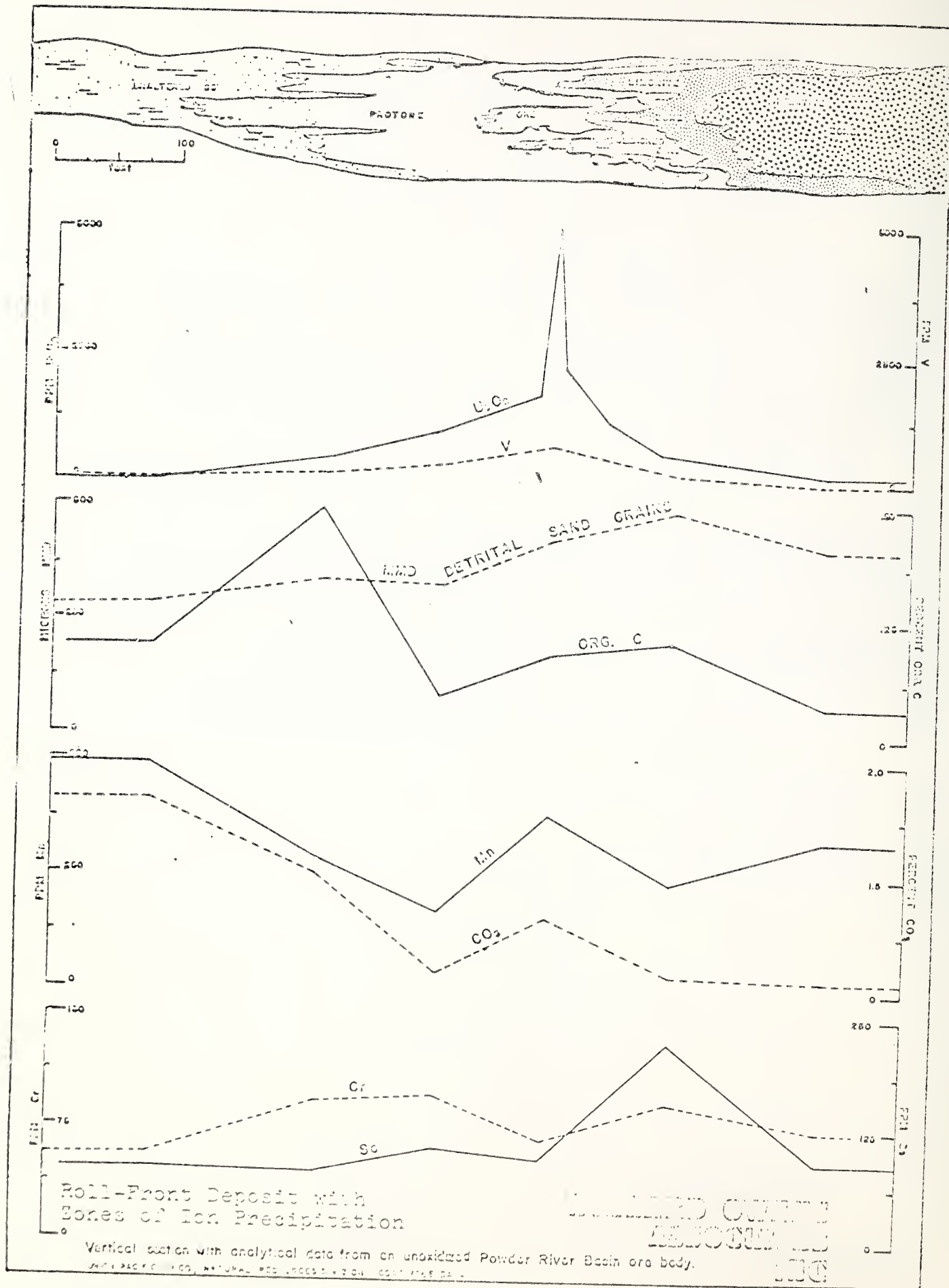
From Rubin (1970)

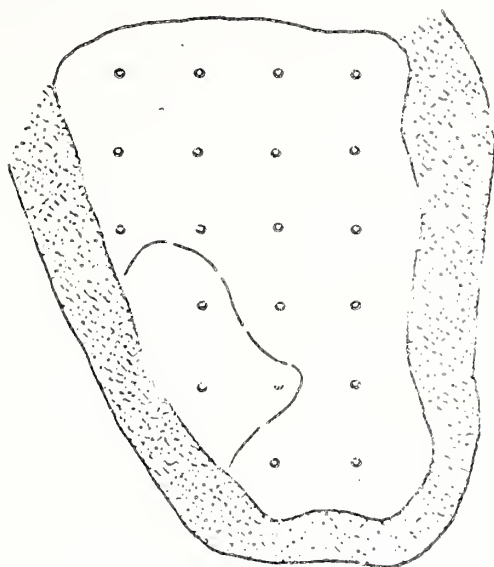
From Boberg 1975 and Rubin 1970

WILLARD OYLER
 ASSOCIATED
 INC.

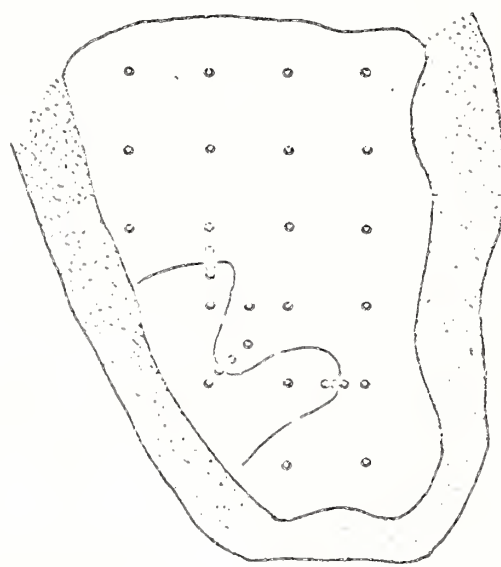
PROJECT NO. 6022

ROLL-FRONT URANIUM DEPOSIT
 WITH ZONES OF ROCK
 ALTERATION

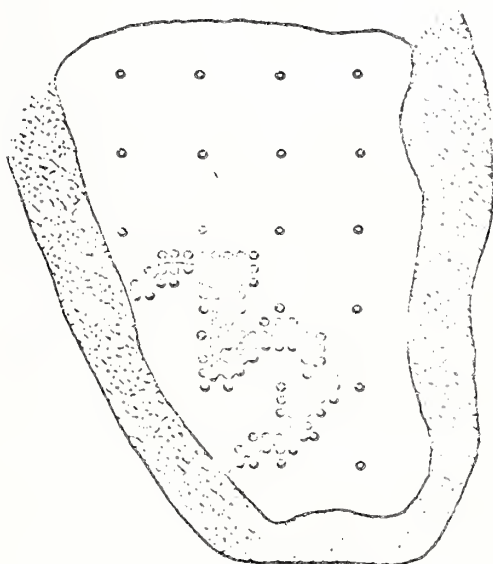




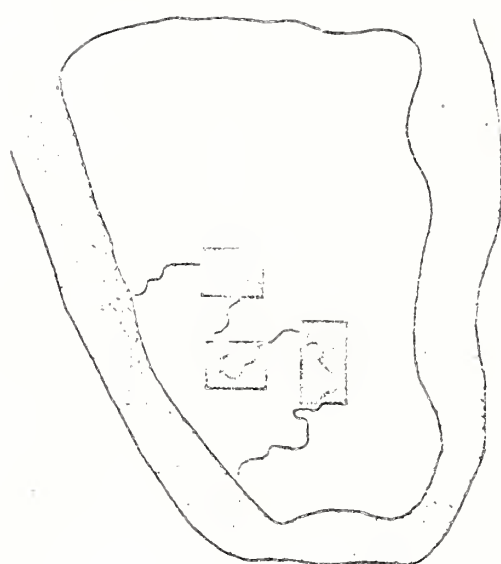
a. Stage 1: Reconnaissance
20 holes



b. Stage 2: Testing the front
25 holes (45 total)



c. Stage 3: Grid drilling along front
90 holes (135 total)



d. Stage 4: Detail drilling of mineralized areas
2000 holes (2135 total)

0 6 12
miles

(650 square miles of Territory outcrop)

Frontal location

• Drill hole in altered sand

• Drill hole in unaltered sand

From Boberg 1975

WILLARD OWENS
ASSOCIATES
INC

PROJECT NO. 6023



HYPOTHETICAL DRILLING
SEQUENCE FOR URANIUM

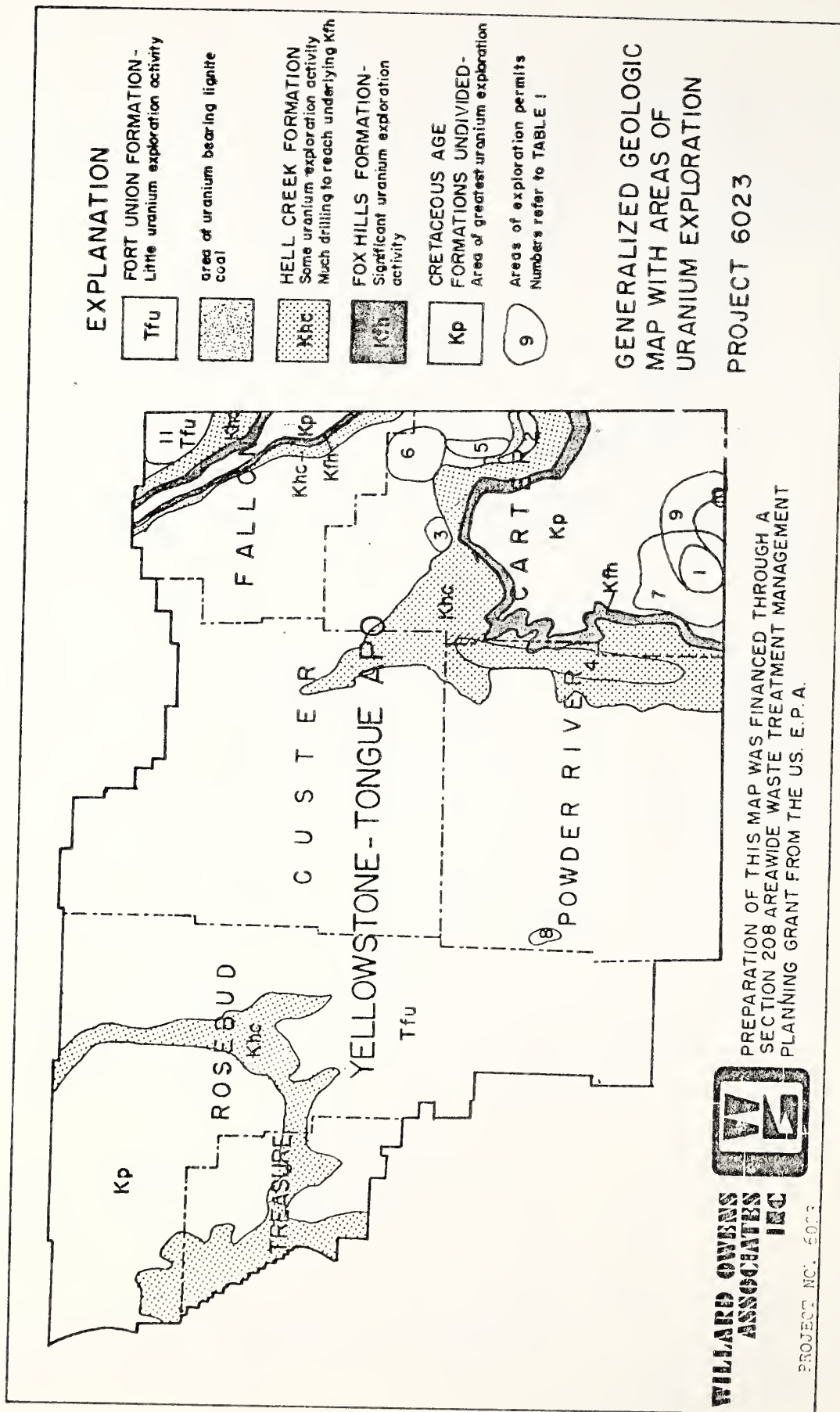
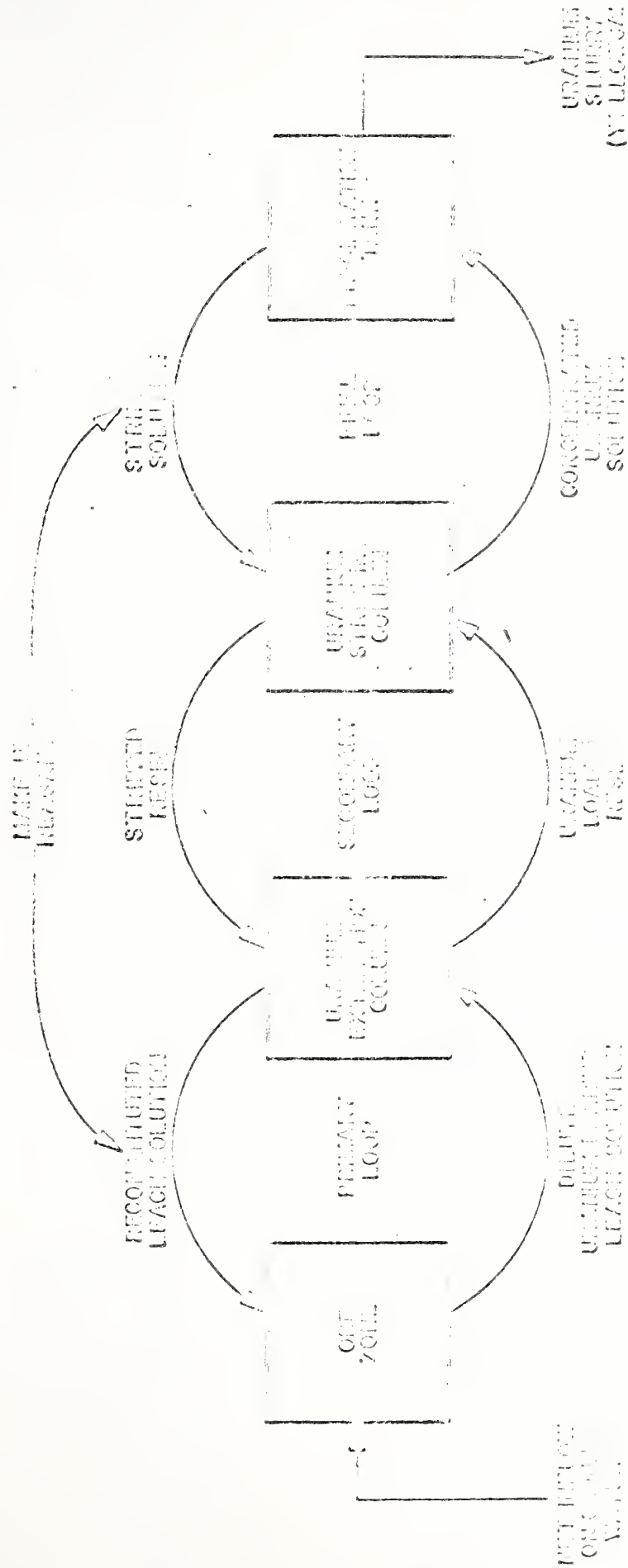


FIGURE IV-4



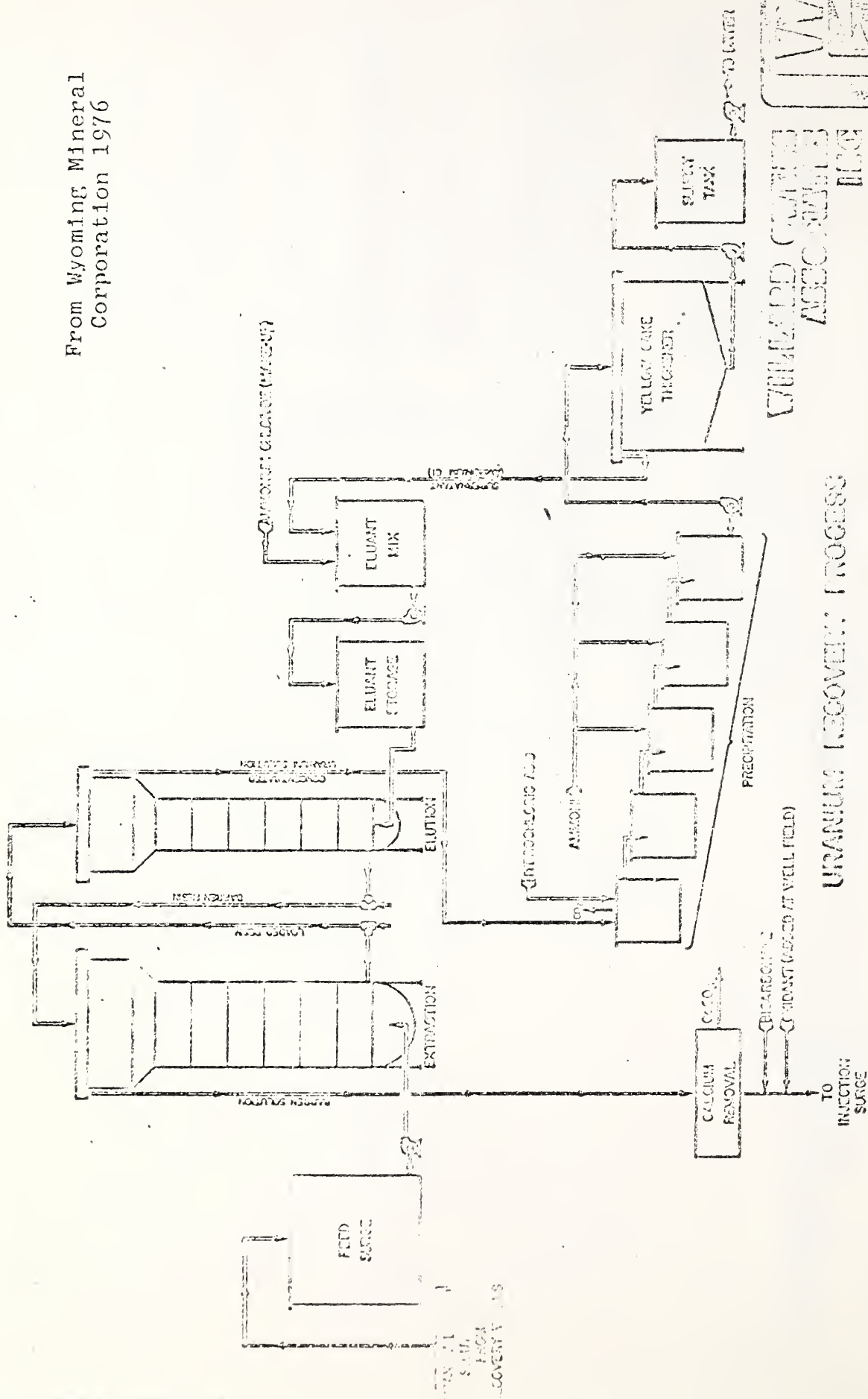
From Wyoming Mineral Corporation 1976

SOLUTION LEACHING PROCESS

PROJECT NO. 6023

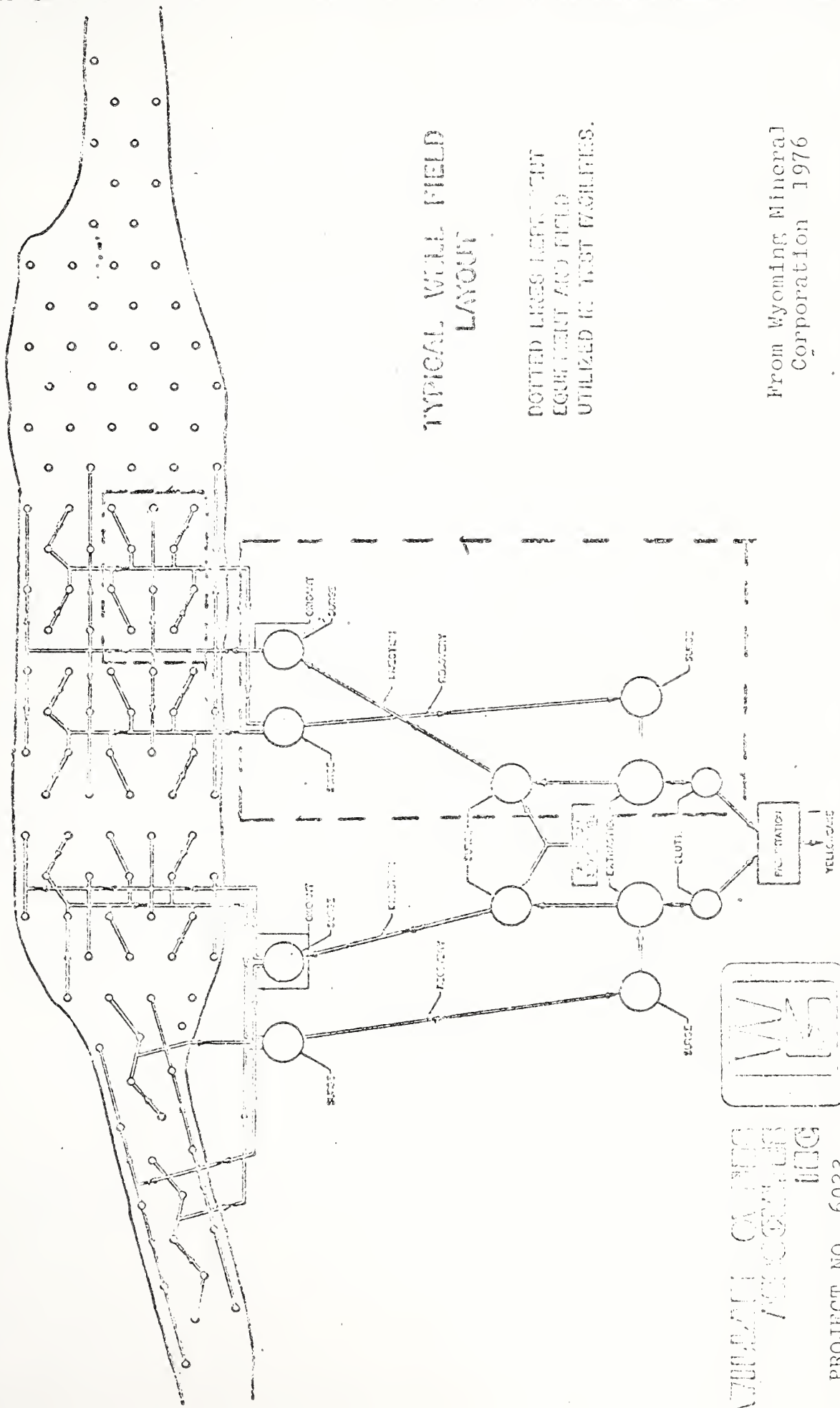
FIGURE IV-5

From Wyoming, Mineral
Corporation 1976



PROJECT NO. 6023

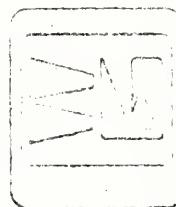
FIGURE IV-6



TYPICAL WELL FIELD LAYOUT

DOTTED LINES REPRESENT
EQUIPMENT AND FIELD
UTILIZED IN TEST WATERS.

From Wyoming Mineral
Corporation 1976



WYOMING MINERAL
CORPORATION

PROJECT NO. 6023

FIGURE IV-7

TABLE IV-1
URANIUM EXPLORATION PERMITS
IN THE YTAPO STUDY AREA

<u>Company</u>	<u>Application Number</u>	<u>Permit Number*</u>	<u>County</u>	<u>Status</u>	<u>Approximate Holes Drilled</u>
Kerr-McGee	1	5	Carter	Expired	-
Kerr-McGee	116	75107	Carter	Renewal of 5	330
Mobil Oil	4	3	Carter	now 75083R	200
Mobil Oil	9	7	Fallon	Expired	36
Mobil Oil	82	77	Powder River	Renewed	20
Felmont Oil	11	15	Carter	now 75134	125-175
Felmont Oil	108	75134	Carter	?	70
Teton Exploration	16	16	Fallon	Inactive	45
American Nuclear	17	13	Carter	Inactive	45
American Nuclear	54	49	Carter	Expired	-
Montana Nuclear	27		Carter	?	-
Exxon	76	72	Carter	Renewed	450
N.R.G.	86	78	Powder River	Expired	25
Pioneer Nuclear, Inc.	136	75128	Carter	?	12

* Single digits indicate 1972 (first year of permit regulations), in multiple digit numbers, first two digits indicate year e.g. 75128 means permit 128 in year 1975.

TABLE IV-1
con't.

The following are numbered to correspond with the numbered areas shown on Figure IV-4.

(1) Kerr-McGee 00005

Original permit was for 80 holes approximately 1200 feet deep, less than or equal to 5 inches in diameter. Drill sites 50 ft. square, or less than 1/10 of an acre. The holes pierce the Lakota (?) formation.

In April, 1974, in reply to State Lands, Kerr-McGee said they had no plans for development.

Kerr-McGee filed for lode claim on 6S 57E 23 B&C. 103 holes drilled in 9S 57E 23.

USGS was concerned that such a large exploratory program would damage the Muddy Sands producing horizon. Kerr-McGee stated that Muddy Sands formation near Alzada was too silty to be a good reservoir rock for oil.

We have a list of where all the 300 holes were drilled should you need them. This exploratory program is the largest in the area except for Exxon, and was all within the Alzada area of Carter County. Exploration has continued into this past summer.

(2) Mobil Oil 00003 "Fox Hills Project"

Originally requested 38 holes 200-1200 feet deep, less than or equal to 5 inches in diameter, near Camp Crook, South Dakota, and Capitol Rock Mt. in Carter County. The holes were to be plugged to 50 feet below the Fox Hills formation. Area of interest is 3S 62E 7,8,9,15,16,17,18,20 and 22.

State requested that prospecting stop in 3S 62E 2-22 because of danger to Capitol Rock, which is deemed a unique geological formation subject to protection.

State Fish & Game sought to exclude Long Pines area of Custer National Forest from exploration because of wildlife habitat.

380 acres around Capitol Rock were withdrawn from "mineral entry" by the Forest Service.

Amendment to permit were requested for more holes in 2S 61E 36 (3holes), 3S 61E 1, 3S 62E 4,5,6,9,10,29,34, and 4S 62E 3,9,10.

Mobil also planned a string of holes 1.25 miles long 30 feet apart in 3S 62E 5,8, and 9. Forest Service became concerned over possible aquifer pollutions and requested state to require at least 100 feet concrete plug at both bottom and top of Fox Hills aquifer. State disagreed over necessity of 100 feet plugs and settled for 50 feet instead.

Mobil is looking for "roll front" type of uranium occurrence located in the Fox Hills sandstone

Mobil has staked claims to 36,620 acres of the 69,996 acres in the Long Pines area.

(3) Mobil Oil 00007 Fallon County "Ekalaka Project"

36 Holes. Very limited project in Ekalaka Hills area.

(4) Mobil Oil 00077 Powder River County

Holes in the Hell Creek outcrop area, again, a much more limited program than in the Long Pines area.

Holes in 1S 54E 9,32,35, 2S 54E 29, 3S 54E 15, 4S 54E 6,32,27, 5S 54E 15,30, 7S 54E 12, and 8S 54E 23.

(5) Felmont Oil Corporation 00015 Carter County "Grassy Butte Prospect"

125 holes 100-500 feet deep on $\frac{1}{2}$ to 1 miles centers. Holes will "collar" Lebo shale member of Fort Union formation and bottom in the Hell Creek. Could drill as many as 173 holes. All in 1S 61E and 2S 61E. Felmont staked mining claims on 1N 61E 14,15,22,23,25, and 26.

(6) Felmont Oil Corporation 75134 Carter County "Box Elder Creek Prospect"

70 holes in first phase. Felmont has leases in 1N 61E and would also drill holes in 1N 60E, 2N 61E, and 2N 62E.

(7) American Nuclear 00013 & 00049 Carter County

45 holes initially to locate uranium bearing sandstone in the Inyan Kara geologic sequence at depths greater than 1200 feet.

Holes on "Claims" in Alzada area. 7,8,& 9S, 56, 57, and 59E. Some holes will be under "TEX" claims.

Montana Nuclear No Permit Granted Because of Bonding Problem.

8S 58E 01 (3holes) 8S 59E 04(4) 5(4) and 6(4) 7S 59E 34(5) 35(7) 26(1) 25(3).

(8) N.R.G. 00078 Powder River County

12 miles southeast of Ashland 25 holes 300 feet deep will be drilled along Otter Creek. 4S 45E 22, and 27.

(9) Exxon 00072 Carter County

213 holes initially on mining property leases and options from Montana Nuclear. 9S 57E, 8S 57E, 8S 58E, 8S 59E, 8S 60E, 9S 60E. 86 additional holes were included. Holes were to be drilled to 1800 feet deep. 151 more holes were added. Because of the depth of mineralization (1800-2000 ft.), Exxon will consider using either conventional deep mining or in place leaching. The earliest possible development date is in the mid to late 80's.

(10) Pioneer Nuclear, Inc. 75126 Carter County

2-5 holes 800 feet deep in 9S 59E 32 & 33, an additional 7 holes were ammended.

(11) Teton Exploration 00016 Fallon County "Ollie-Carlisle Project"

30 seismic shot holes at original depth of 200 feet. 10N 61E 8, and 9.

SECTION V

GROUND WATER CONTAMINATION DUE TO PETROLEUM
EXPLORATION AND DEVELOPMENT

V. GROUND WATER CONTAMINATION DUE TO PETROLEUM
EXPLORATION AND DEVELOPMENT

GEOLOGY OF DEPOSITS

The oil fields in the project area occur as clusters in three separate areas. These areas are (Figure I-2):

- 1) an area in the very northwestern portion of Rosebud county,
- 2) an area in southeastern Powder River county, and
- 3) an area trending northwest to southeast through Fallon county.

Production from Fallon county is coincident with a zone parallel to the axis of the Cedar Creek Anticline. The oil is concentrated along the crest of the anticline where it has been structurally trapped. The field is 57 miles long in Montana alone. Production is from porous carbonate rocks of Ordovician to Mississippian age. The oil fields occur at depths from 7,300 to 9,600 feet, three to four times the depth of gas-producing sand zones directly above the oil.

In contrast to the structural conditions which trap the oil in the Cedar Creek anticline, the oil in Powder River county was trapped stratigraphically. The Bell Creek field, which was the first giant oil field discovered in the Powder River Basin in over 50 years, illustrates the relationships involved. The Bell Creek field is located in very southeastern Powder River county and is

elongate in a northeast-southwest direction parallel with the strike of the rocks, which dip northwestward towards the axis of the Powder River Basin (Figure V-1). The oil is in the Muddy Sandstone of early Cretaceous age, which is unusually thick and permeable here as compared to areas further south of Wyoming. Previous to the discovery of the Bell Creek field, only one Muddy Sandstone oil field, Ranch Creek, had been developed before 1967 in Montana. Production from the Ranch Creek field was disappointing. However, a wildcat that was drilled five miles northeast of Ranch Creek along the structural and stratigraphic strike resulted in the Bell Creek discovery.

Petrographic analysis has confirmed that the main reservoir at Bell Creek is a barrier-bar deposit (Figure V-2). As such, the dominantly fine-grained, permeable sand reservoir with an average thickness of twenty feet, is practically isolated by shales from other sands (Figures V-3 & 4). Porosity reaches 33%, and permeabilities are as great as 13,500 milli-darcies. Drilling which followed Bell Creek resulted in important discoveries at eight other wildcat locations in the area.

The oil in Rosebud county in the northwestern part of the project area has different geological controls from that of the other two areas. It occurs in the Tyler formation, which contains the major reservoirs of central Montana and consists of channel deposits filling valleys due to stream incision into the underlying

Heath shale. The major fields in the area have been located where these elongate channel deposits coincide with anticlinal axes. Consequently, the oil was concentrated in combination structural-stratigraphic traps. Oil in both Rosebud and Powder River counties occurs at depths from 4,500 to 5,000 feet.

PETROLEUM EXPLORATION AND GROUND WATER CONTAMINATION

The methods of exploration for oil first used involved the search for "red flags", which were characteristically seeps of oil, tar, or other indicators at shallow depth. Following the location of these "red flags", it was a simple matter to drill in a down-dip direction to search for the source of the hydrocarbon. However, oil explorationists rapidly recognized that oil is frequently concentrated along the structural highs of domes or anticlines. Such structures then became major targets of exploration. Through time, it was learned that other preferred zones of oil concentration existed. For example, stratigraphic traps (pinchouts of permeable reservoirs in updip directions), fault truncations of reservoir rocks, salt domes, and porous limestone reservoirs were recognized as important targets. Such targets were generally located using traditional geologic mapping methods.

However, in order to determine structural and stratigraphic conditions more easily at depth, new methods were developed. Probably the most important of the geophysical methods is seismic, which is probably the most commonly used method today, but magnetic and gravity surveys are also important. Sedimentologic studies to predict sand-reservoir geometry and trend

are valuable ancillary tools. They augment the classical stratigraphic approaches to regional investigations.

Seismic techniques involve inducing energy into the earth's crust where it is reflected and refracted by the various subsurface geologic layers back to various pressure transducers where the travel times are recorded. This data is then interpreted to locate areas of geologic structure and stratigraphic variation which could serve as potential traps for petroleum. The most common technique of energy induction is to discharge explosives in drill holes, referred to as seismic shot holes.

The drilling and the explosive detonations can pollute the ground water by several means:

1. The inter-connection of aquifers of varying water quality;
2. The inter-connection of surface water run-off and ground water aquifers;
3. Chemicals introduced into the ground water as a result of the detonation of the explosive placed in the drill hole.

Some ranchers and farmers believe that seismic exploration will alter the subsurface by causing a change in permeability in the vicinity of wells. It is our opinion that there is little risk of change in permeability unless the explosion is very close to an existing well. In some cases the explosion may increase the permeability

due to the vibration removing the incrustation in the well casing. In other cases the explosion may cause a collapse of the well itself or sanding conditions. However, it is our general conclusion that the vibration from an explosion will not change the subsurface significantly or cause an area wide change in permeability.

In an area of resident complaints due to seismic activity affecting the quality of water or well yields, it is difficult to scientifically study these areas after the fact, because no baseline data is generally available to compare to results after seismic exploration. Residents and water well drillers commonly do not maintain records of water quality or accurate well yield. About the best that can be done in these situations is to evaluate the existing geology and type of seismic exploration activity to determine whether or not there is even the potential of change.

Old seismic holes that can be located can be sounded to determine their depth relative to existing wells. This information can be evaluated to determine the potential of inter-connection of ground water aquifers.

The pollution hazard due to the explosives utilized and changes to formation yield are difficult to determine. The best way to study these effects is to conduct a baseline study prior to seismic investigation and then concurrently with and after the exploration program conduct a quality and quantity monitoring program.

Oil exploration wells are subject to the contamination problems previously discussed under modes of ground water contamination, and impose additional problems as they encounter brine-producing sands and formations under high pressure. Blow-outs are a constant threat of contamination to ground water aquifers. Breaks in casing or the sloughing off of material on the outside of the casing can result in a blow-out if pressurized hydrocarbons are encountered (Figure V-5).

Several strings of casing through the zone of water production can help protect ground water aquifers. Generally, a minimum of two casing strings are adequate. However, additional strings of casing might be needed if heaving shales or lost circulation are encountered or if drilling pressures are abnormally high. Adequate mud pressure must be maintained to prevent surficial blow-outs. Blow-outs in natural gas wells are especially hazardous if the gas contains sizable quantities of hydrogen sulphide.

Proper disposal of oil field brines has always been a problem. Disposal of brines through disposal wells and increased flooding by water can lead to movement of the brines up abandoned oil wells and penetration into the fresh water aquifers.

PETROLEUM DEVELOPMENT AND GROUND WATER CONTAMINATION

Three types of oil recovery are commonly distinguished - primary, secondary, and tertiary.

Primary recovery is that oil and gas produced by natural reservoir energy forces. The primary reservoir energy sources that cause oil to move toward a well are gravity, elastically-compressed reservoir rock, hydrostatic fluid pressure, compressed fluids, gas dissolved in oil, and free gas under pressure. Through these energy sources, a field may yield 20 to 30 percent of the oil in place, which is that fraction of the pore space filled with oil. Consequently, more than two-thirds of the oil in a field will not be recoverable through primary methods.

Secondary recovery is that oil or gas produced by an artificial restoration of energy after primary production ceases or is significantly reduced. Secondary recovery usually follows, but in some fields may be conducted concurrently with primary recovery methods. Waterflooding is the principal method of secondary recovery, but other ways of repressuring the reservoir are also included. Waterflooding is simply the injection of water into the reservoir through certain wells and withdrawal of the oil and gas from other wells. The oil or gas is pushed or driven towards the withdrawal wells by a bank of water. Through waterflooding, another one-third of the oil in place may be withdrawn from the reservoir.

After primary and secondary recovery processes are completed, as much as one-half, and possibly more, of the original oil in place will still be in the reservoir. This oil is partially removed through tertiary or enhanced recovery methods.

Tertiary oil recovery is of importance to the Yellowstone Tongue APO project because Gary Operating Company is initiating a pilot recovery test at the Bell Creek field, and enhanced recovery may be used elsewhere in the project area in the future. Gary plans to begin chemical injection through their injection wells within the next several months. Then it will require 9 to 12 months more to obtain the test results. They will employ a micellar-polymer test.

Three general types of enhanced recovery methods are available -- miscible displacement, thermal recovery, and chemical flooding. These types are diagrammatically shown in Figure V-6.

The purpose of the miscible displacement recovery method is to inject a substance that is miscible with the reservoir oil. This substance overcomes those capillary forces locking residual oil droplets in the interstices. It permits the movement of the injected fluid, which dislodges the oil and moves it to producing wells. Naptha, kerosene, and gasoline are miscible with typical reservoir oils, as are liquified petroleum gas products such as ethane, propane, and butane. Liquid hydrocarbons are miscible with oil immediately upon contact -

they have first contact miscibility. In contrast is multiple contact miscibility, in which high pressure gas or enriched gasses are injected, and successive encounters with the oil increases its mobility.

The uses of naptha, kerosene, and other miscible hydrocarbons are usually economically unpractical. However, propane is commonly economically feasible and thus is the method most often used in the miscible displacement, enhanced-recovery method.

The purpose of thermal recovery methods is to heat the reservoir and the oil within it to decrease the oil viscosity. Steam is often injected. By reducing the viscosity, a greater sweep efficiency is obtained. Basic methods of thermal recovery are hot-water flooding, cyclic steam injection, and steam drive. An additional thermal recovery technique is in situ combustion. In this method, the oil in the reservoir is ignited and the fire is sustained by air injection. The term "forward combustion" is often applied to this process. In forward combustion, the flame front is advancing in the same direction as the air movement is, from the injection well to the producing well. The increased temperature reduces the viscosity of the oil and it is driven towards a producing well.

The micellar-polymer solution flood processes are the most promising tertiary recovery techniques. They have good sweep efficiency plus they displace more of the contacted crude oil in the reservoir. Their primary

drawback is that they require large amounts of expensive chemicals.

A micellar solution can be described as a micro-emulsion. An emulsion is a mixture of mutually insoluble liquids in which one is dispersed in droplets throughout the other, for example, oil in water. In a micro-emulsion, the immersed particles are of microscopic size.

A micellar solution is a micro-emulsion of surfactant and water. A surfactant is a surface-active agent (or a soap-type substance) that has the ability to change the interfacial tension of the solution. Surfactants have molecules with one end attracted to oil and the other end attracted to the water. If the surfactant is mixed with water at a low concentration, it forms a solution. If the concentration is increased over some critical amount, the surfactant molecules cling together in clusters called micelles. If oil is mixed into this surfactant-water system, the micelles can dissolve it by forcing microscopic-size droplets into the center of the micelles. These are called swollen micelles. Thus, a micellar solution is formed of surfactants which essentially wash the oil from the interstices of the sedimentary formation. Alcohol is commonly added to the micellar solution as a co-surfactant. It helps adjust the viscosity and helps the micelles solubilize more oil or water and also reduce adsorption of the surfactant to the reservoir rock. Also, an electrolyte is commonly added to aid in the adjustment of the viscosity.

The micellar-polymer process which Gary Operating Company plans to employ in the Bell Creek field enhanced recovery operation is very simple. First, a period of pre-flushing will occur in which saline water is injected through the reservoir prior to the introduction of the micellar slug. Next, the micellar solution is injected into the reservoir. In the Bell Creek field, this solution will consist of sulphonated crude oil which will develop miscibility with the oil remaining in place. A polymer will be added for viscosity control. The polymer will be a polyacrylamide. The composition of the micellar slug will be a chain hydrocarbon with a SO_3H molecule on one end.

A significant factor involving the potential for ground water pollution in the micellar-polymer process is that of toxicity of the solutions. Table V-1 provides comparisons of materials used in micellar-polymer floods. The water quality criteria were developed by the EPA for the various uses of water in relation to these materials, along with estimated or test-derived concentrations of reservoir water after use of these materials. The table clearly shows that, after enhanced recovery operations, concentrations of these materials in reservoir water will always be excessive. Consequently, it is of the utmost importance that these materials do not migrate out of the reservoir.

An important element in this is that toxicity of all but a very few of the chemicals, and also their degradation products, are unknown, according to the Environmental

Protection Agency. Of course, toxic effects are concentration dependent. Because of filtration, dillution, and adsorption processes, chemicals released from an oil reservoir will decrease in concentration with distance travelled. Therefore, negligible concentrations may occur only a very short distance away. Furthermore, although much is known about the chemical compositions and effects on water quality of the chemicals themselves, their synergistic effects are not known in most instances. At the very least, surfactants, co-surfactants, and other chemicals used in enhanced recovery processes will impart undesirable tastes or odors to ground water and in some instances they will definitely be carcinogenic or toxic. In spite of these factors, we believe that the geologic environment, and especially the stratigraphic isolation of the Bell Creek field, is a factor which limits the possibility of ground water pollution in the surrounding aquifers from this source.

Micellar-polymer slugs were successfully used almost ten years ago. Forty-five to fifty percent of the post-waterflood oil has been recovered in tests employing micellar flooding.

Micellar solutions cost from \$8.00 to \$15.00 a barrel and, for this reason, are currently uneconomical for many fields. When the price of oil ultimately rises, micellar-polymer methods of enhanced oil recovery will undoubtedly increase.

A breakdown of active enhanced recovery projects in the United States is currently as follows:

Carbon Dioxide	9
Miscible Hydrocarbons	13
Micellar-Polymer	27
Steam	85
Combustion	21

These are in Pennsylvania, Illinois, Kansas, Oklahoma, Texas, Nebraska, Wyoming, Montana, and California. It should be emphasized that micellar-polymer projects are only in the testing phase currently and for full scale operations to be undertaken, much more testing will be necessary.

For methods of secondary and tertiary recovery, it is, of course, essential that the flow parameters and transmissability of the oil-and water-bearing strata be known. This understanding is sometimes achieved by the use of radioactive tracers that are injected into the strata. The movement of these tracers is monitored by a system of wells. The movement of water can thus be estimated for the practicality of flooding the oil field.

In itself, this method does not present a hazard as long as the radioactive material is confined to the oil-bearing strata and does not enter an aquifer. The potential for hazard can arise through possible casing leaks, spillage, and improper disposal of radioactive, tracer-bearing water as it emerges from the well.

It is thus important to know exactly what radioactive material is used, its half life and concentration, and exactly what effect it will have on potable water.

Water emerging from a well containing radioactive material should be recirculated back into the oil bearing zone to prevent contamination of surface water. Continuous monitoring should be maintained to determine if the radioactive water is somehow entering strata other than the oil bearing strata, whether by means of a casing break, fractures in the rock, solution cavities, or other means.

Another use of radioactive material in oil development is as a determination of formation permeability. Permeability in an uncased well can be determined by pumping down radioactive mud and then lowering a counter down the well. High radioactivity corresponds to areas with the highest penetration of the radioactive mud. The possibility of radioactive mud entering ground water aquifers exists and is a possible source of ground water pollution.

In some cases, oil field activity can bring about an increase of pre-existing sources of contamination of ground water. Such instances can include ground subsidence, additional fracturing, increasing potential for earth movement, and the creation of situations for oil seepages to occur.

As an oil field is pumped, subsidence can result when large amounts of fluid are withdrawn. This subsidence can in turn bring about fracturing, local flooding, and changes in the water table.

Subsurface blasting might be used to increase size of fractures and increase production.

As water is removed or added to the subsurface, a balance of pressures are affected that can result in earthquakes. An example of this is the earth movement experienced in Denver due to the deep well injection of wastes. Earthquake studies have taken place in northwest Colorado using this principal. Also as water and oil are removed, there is a chance of earth movement.

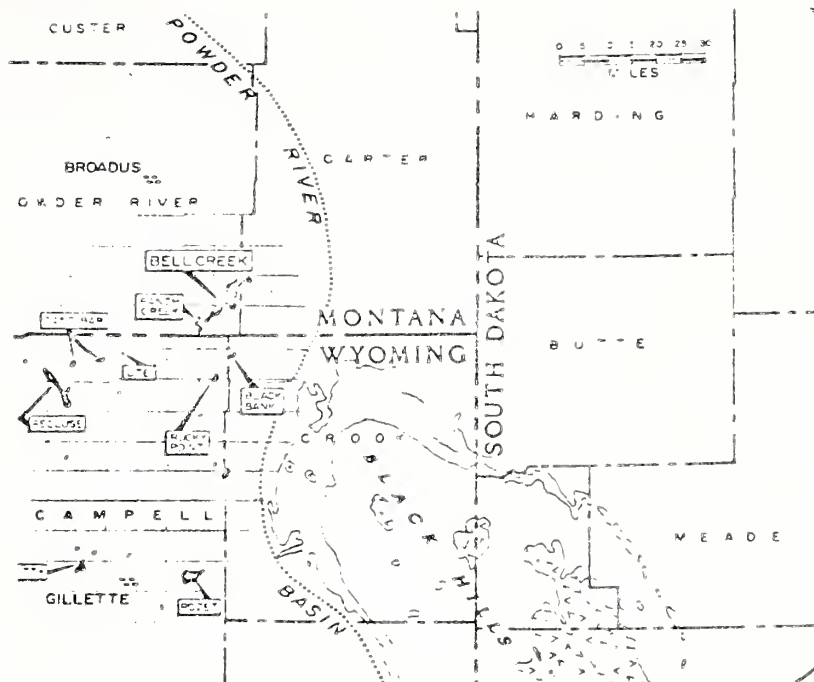


FIGURE V-1: Location of Bell Creek Field

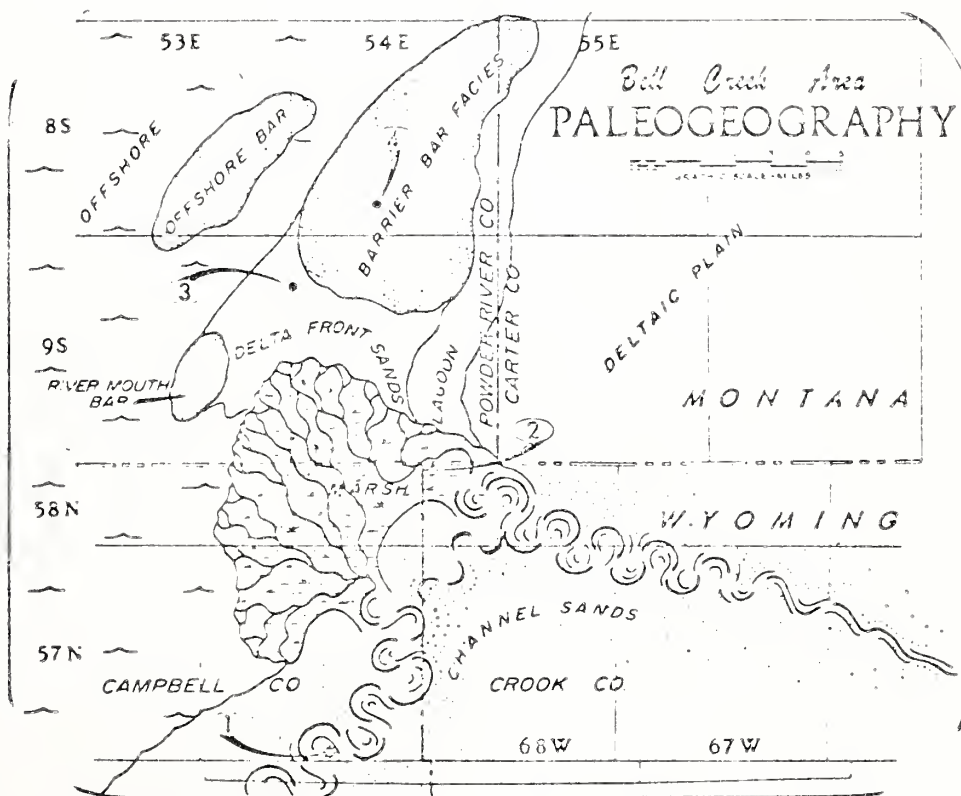


FIGURE V-2: Map showing Barrier Bar is Principal Bell Creek Facies

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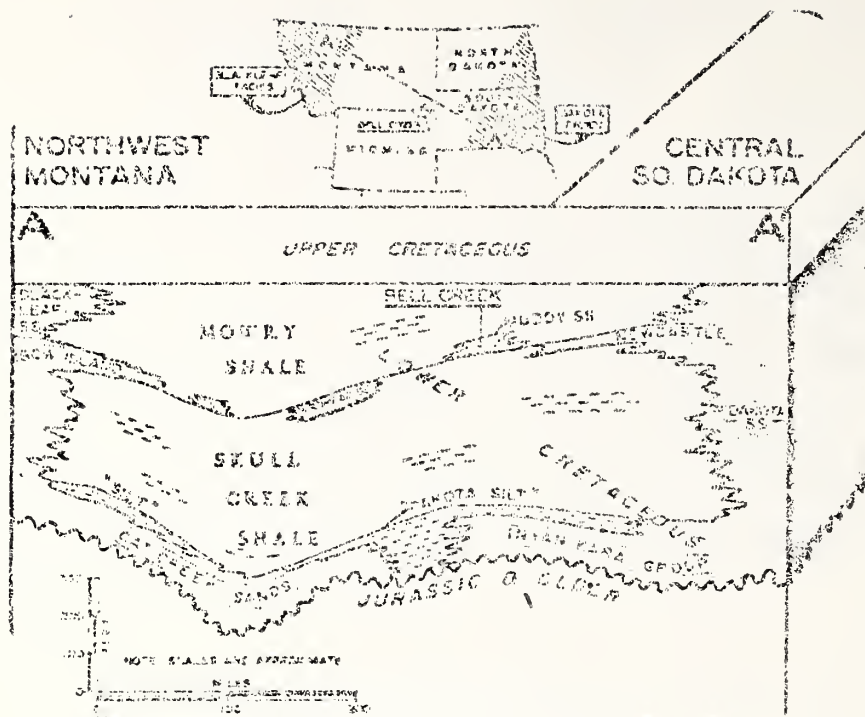


FIGURE V-3: Block Diagram Showing Isolation of Muddy Sand

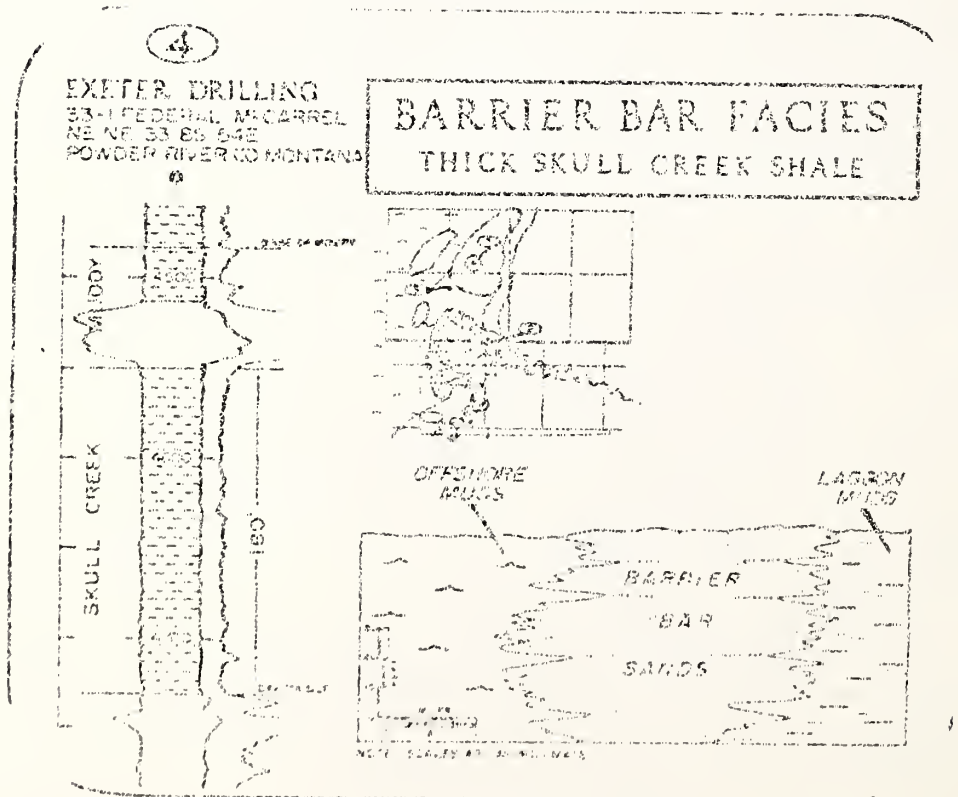
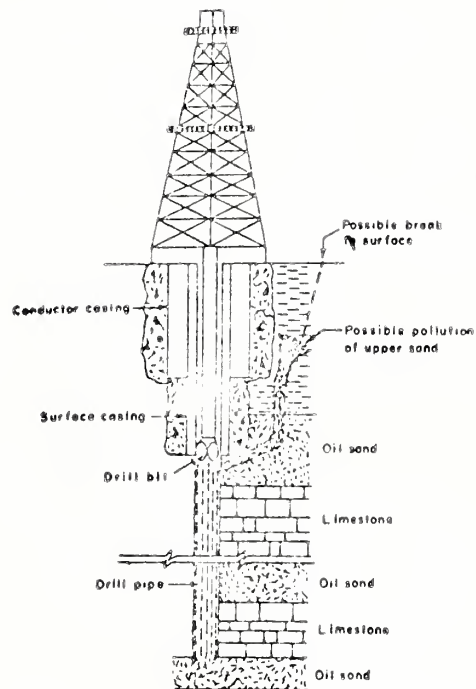


FIGURE V-4: Barrier Bar Facies and Thick Skull Creek Shale

WILLIAM D. GIBBS
ALBUQUERQUE
N.M.



WELL BLOWOUTS CAN PERMIT AQUIFER CONTAMINATION

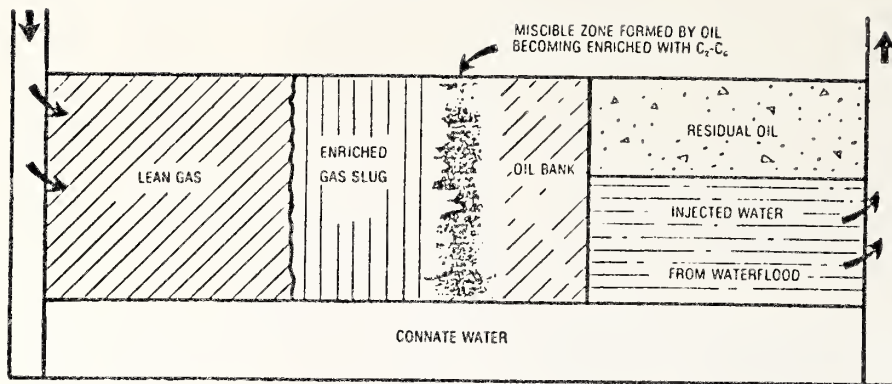


From Campbell and Lehr, 1973

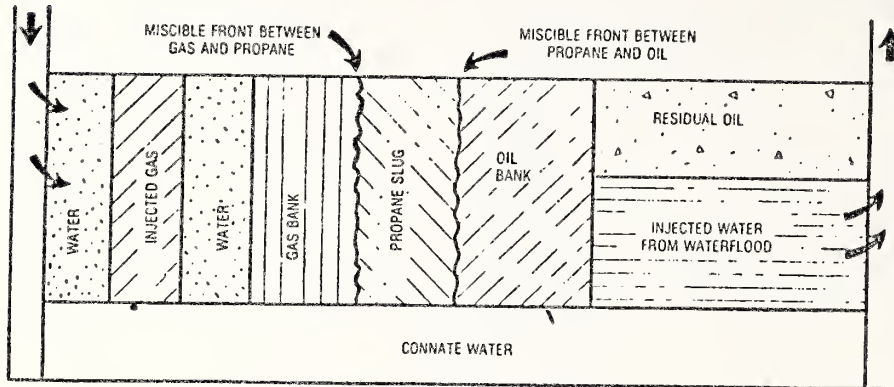
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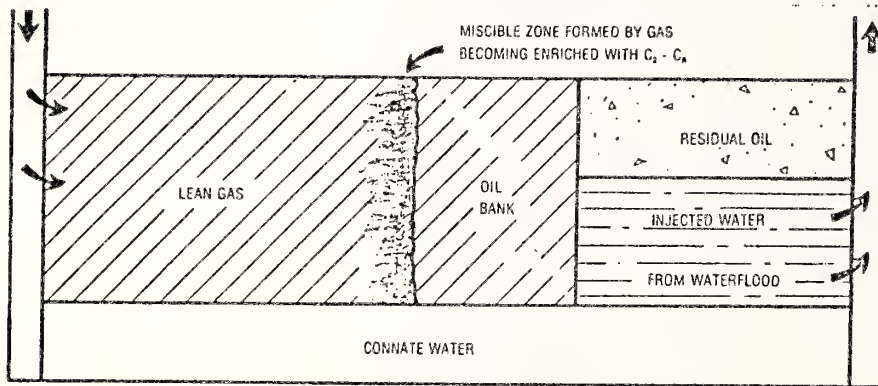
FIGURE V-5



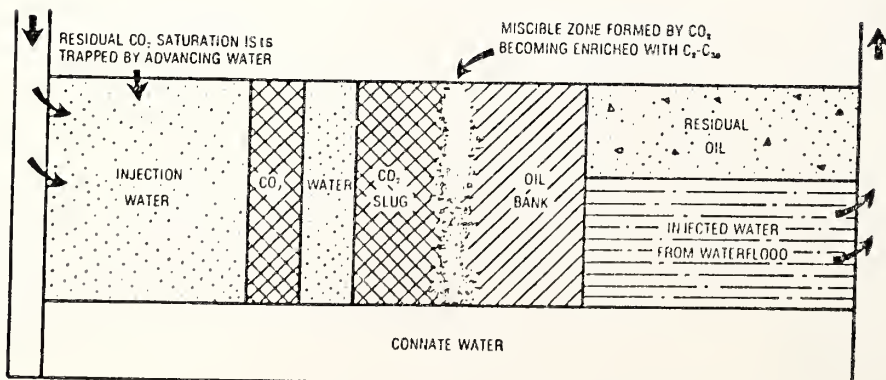
Enriched gas process



Propane slug process

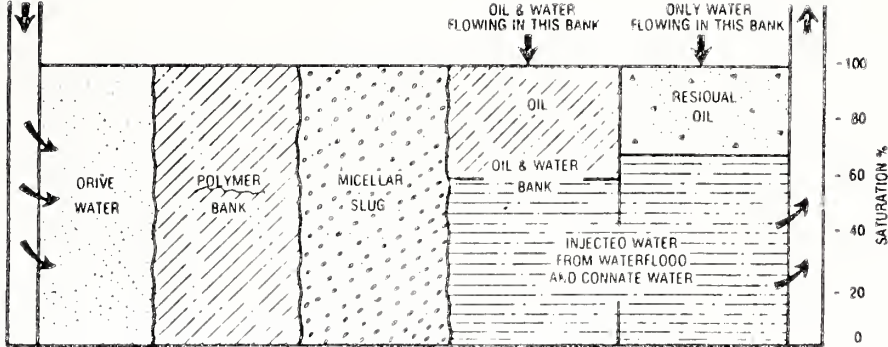


Lean Gas Process

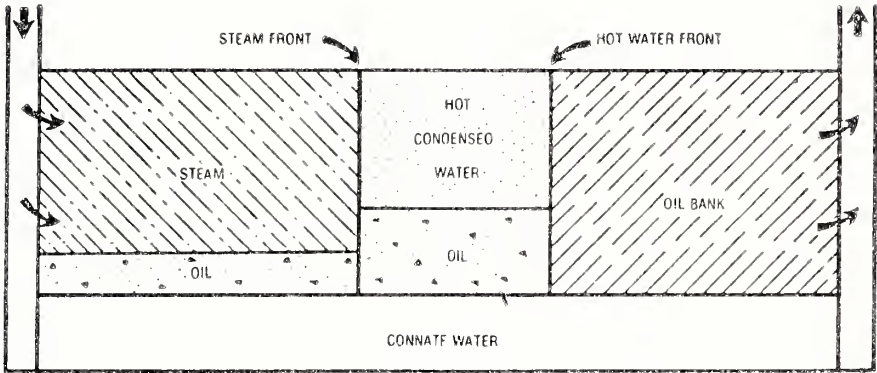


CO_2 process

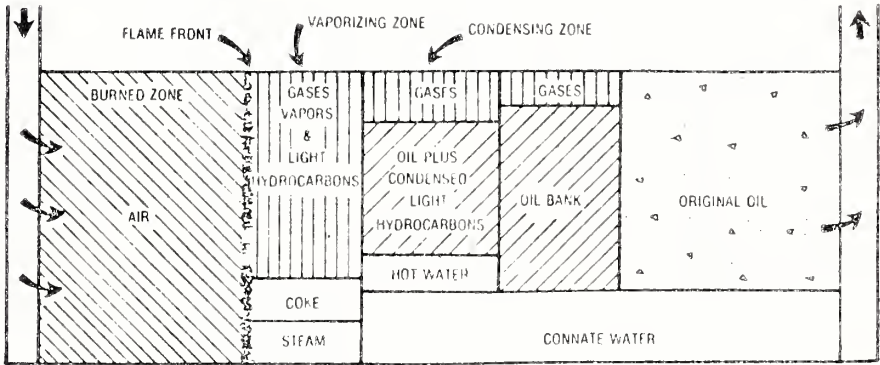
DIAGRAMS ILLUSTRATING
ENHANCED RECOVERY
PROCESSES (cont.)



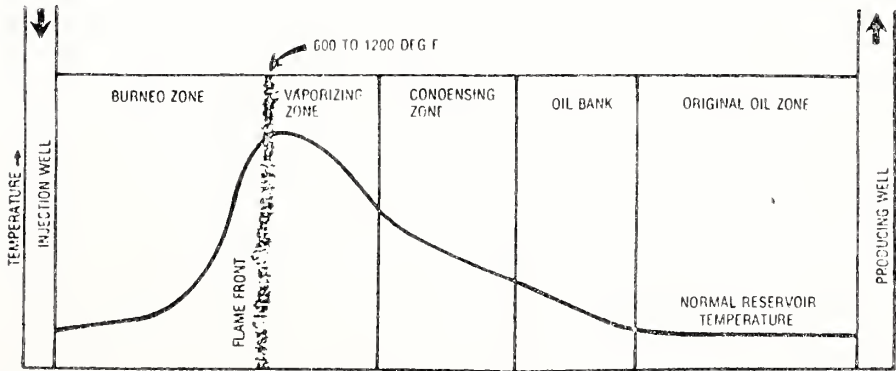
Micellar flood process



Steam drive displacement



Combustion process



Temperature profile of combustion process

TERTIARY OIL RECOVERY

COMPARISON OF CHEMICALS WHICH MAY BE PRESENT IN PROCESSES WITH WATER QUALITY CRITERIA

MATERIAL	WATER QUALITY CRITERIA ^a				MAXIMUM RESERVOIR WATER AFTER TERTIARY RECOVERY ^b (milligram/liter)	PROCESS CODE ^c
	AI	AL	FW	WS		
Dioctadecyl dimethyl ammonium chloride	-	-	0.2 mg/l	0.5 mg/l	375 - 1900 mg/l	S
Dodecyl trimethyl ammonium chloride	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Hexadecyl trimethyl ammonium chloride	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl phenoxypolyethoxy ethanol	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
p-Chloroaniline sulfate laurate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
p-Toluidine sulfate laurate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Polylglycerol monolaurate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Glycerol distearyl phosphate monomylate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
n-Butylamine oleate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Nonobutylphenol sodium sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Polyoxyethylene alkyl phenol	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Morpholine stearate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Pentaerythritol nonostearate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Dihexyl sodium succinate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Diethyleneglycol sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
n-Dodecyl-diethyleneglycol sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sodium glyceryl monolaurate sulfate	-	-	0.2 mg/l	0.6 mg/l	375 - 1900	S
Sodium sulfate octylethylenediamide	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alphabetaisulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl aryl sulfonate detergent	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl aryl naphthene sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Hexadecylphthalene sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sodium lauryl sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Triethanolamine laurate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Triethanolamine myristate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Triethanolamine oleate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Fusel oil	-	-	-	-	200 - 4000	C
Phenol	-	-	<1 mg/l ^a	1 mg/l	200 - 4000	C
p-Nonyl phenol	-	-	-	1 mg/l	200 - 4000	C
Isopentanol	-	-	-	-	200 - 4000	C
2-Pentanol	-	-	-	-	200 - 4000	C
Cresol	-	-	<0.07 mg/l ^a	1 mg/l	200 - 4000	C
Daryl alcohols	-	-	-	-	200 - 4000	C
Ethanol	-	-	-	-	200 - 4000	C
Isobutanol	-	-	-	-	200 - 4000	C
n-Butanol	-	-	-	-	200 - 4000	C
Cyclohexanol	-	-	-	-	200 - 4000	C
1-Hexanol	-	-	-	-	200 - 4000	C
1-Hexanol	-	-	-	-	200 - 4000	C
1-Octanol	-	-	-	-	200 - 4000	C
1-Octanol	-	-	-	-	200 - 4000	C
Isopropanol	-	-	-	-	200 - 4000	C
Formaldehyde	-	-	-	-	200 - 4000	B/C
Glutaraldehyde	-	-	-	-	200 - 4000	B/C
Paraformaldehyde	-	-	-	-	200 - 4000	B/C
Amides	-	-	-	-	200 - 4000	B/C

a - AI = Air Emission; AL = Air Load; FW = Fresh Water; WS = Waste Stream
 b - Maximum Reservoir Water After Tertiary Recovery (milligram/liter)
 c - C = Corrosive; S = Severe; B/C = Both Corrosive and Severe

TERTIARY OIL RECOVERY

COMPARISON OF CHEMICALS WHICH MAY BE PRESENT IN PROCESSES WITH WATER QUALITY CRITERIA

MATERIAL	WATER QUALITY CRITERIA*				RECOMMENDED WATER PIT/TERTIARY RESIDUES ^b (mg/litres/litre)	PRECED- CULEN
	MI	AL	FW	WS		
Dietazetyl dimethyl ammonium chloride	-	-	0.2 mg/l	0.5 mg/l	375 - 1900 mg/l	S
Dodecyl trimethyl ammonium chloride	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Dodecyl trimethyl ammonium chloride	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Allyl dimethylammonium ethoxide	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
p-chlorophenolic sulfonic laurate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
p-Toluene sulfonic laurate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Methylphenyl sulphonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Glycerol dioctadecanoate monooxalate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
n-Octadecanoic acidamide	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Hexadecyl tri-n-phenyl sodium sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Endoheptachlorine alkyl phenol	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Permethrin acetate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Pentachlorophenyl monosulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Dihexyl sodium succinate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Diethylene glycol sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
n-Hexadecyl-dimethyldiphenyl sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sodium glyceryl monolaurate sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sodium stearate octylstyrylaniline	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alpha-linolenic sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl aryl sulfonate detergent	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl aryl naphthenic sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Hexadecylcapthalene sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sodium lauryl sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Tetradecanolamine laurate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Tetradecanolamine myristate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Tetradecanolamine oleate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Fuel oil	-	-	-	-	200 - 4000	C
Phenol	-	-	<1 mg/l ^a	1 µg/l	200 - 4000	C
p-Nonyl phenol	-	-	-	1 µg/l	200 - 4000	C
Isopentanol	-	-	-	-	200 - 4000	C
1-Pentanol	-	-	-	-	200 - 4000	C
Crude oil	-	-	<0.07 mg/l ^a	1 µg/l	200 - 4000	C
Dipyl alcohols	-	-	-	-	200 - 4000	C
Ethanol	-	-	-	-	200 - 4000	C
Isobutanol	-	-	-	-	200 - 4000	C
n-Butanol	-	-	-	-	200 - 4000	C
Cyclohexanol	-	-	-	-	200 - 4000	C
1-Hexanol	-	-	-	-	200 - 4000	C
2-Hexanol	-	-	-	-	200 - 4000	C
1-Octanol	-	-	-	-	200 - 4000	C
3-Octanol	-	-	-	-	200 - 4000	C
Isopropyl alcohol	-	-	-	-	200 - 4000	C
Formaldehyde	-	-	-	-	200 - 4000	B/C
Glutaraldehyde	-	-	-	-	200 - 4000	B/C
Paraformaldehyde	-	-	-	-	200 - 4000	B/C
Amides	-	-	-	-	200 - 4000	C
Amino compounds	-	-	-	-	200 - 4000	C
Sorbitan fatty ester	-	-	-	-	200 - 4000	C
Ketones	-	-	-	-	200 - 4000	C
Alkylated aryl compounds	-	-	-	-	200 - 4000	C
Anthracene compounds	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Alkyl phenols	-	-	<1 mg/l	(no odor or visible film)	950 - 11250	H
Benzene	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Toluene	-	-	<0.25 mg/l ^a	(no odor or visible film)	950 - 11250	H/T
Crude oil (sour)	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Crude oil (sweet)	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Overheads from crude column	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Side cuts from crude column	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Gas oils	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Straight run gasoline	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Xerocene	-	-	<1 mg/l ^a	(no odor or visible film)	950 - 11250	H
Liquidified petroleum gas	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Naptha	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H

1. *Species*: *Agrostis alba* (L.) Steud.
 2. *Family*: Poaceae
 3. *Genus*: *Agrostis*
 4. *Species*: *alba*
 5. *Authority*: (L.) Steud.
 6. *Number*: 1000
 7. *Location*: Fresh water, 1000 m. alt.,
 8. *Country*: USSR, Khabarovsk Krai,
 9. *District*: Khabarovsk, 10 km. S. of
 10. *Station*: Khabarovsk, 10 km. S. of
 11. *Collector*: V. I. Kuznetsov, 1950,
 12. *Number*: 1000
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 100. *Number*: 1000

TABLE V-1

MATERIAL	WATER QUALITY CRITERIA				MAX. RESERVOIR WATER AFTER TERTIARY RECOVERY (mg/l)	PROCESS CODE
	AI	AL	FW	WS		
Heptane	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Octane	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Pentane	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Propane	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Cyclohexane	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Tip top crude	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Synthesized hydrocarbons	-	-	(no odor or visible film)	(no odor or visible film)	950 - 11250	H
Diaphanous compounds	-	-	<0.1 mg/l ^a	(no odor or visible film)	950 - 11250	H
Amines	-	-	-	-	5 - 100	P
Carboxymethylcellulose	-	-	-	-	5 - 100	P
Carboxyvinyl polymer	-	-	-	-	5 - 100	P
Desoxyribonucleic acid	-	-	-	-	5 - 100	P
Glycerin	-	-	-	-	5 - 100	P
Polyacrilamide	-	-	-	-	5 - 100	P
Polyethylene oxide	-	-	-	-	5 - 100	P
Polyisobutylene in benzene	-	-	-	-	5 - 100	P
Polysaccharides	-	-	-	-	5 - 100	P
Rheoplectic polymer	-	-	-	-	5 - 100	P
Rubber in benzene	-	-	-	-	5 - 100	P
Starch	-	-	-	-	5 - 100	P
Aldoses B series	-	-	-	-	5 - 100	P
Aldoses L series	-	-	-	-	5 - 100	P
Dextrans	-	-	-	-	5 - 100	P
Ketoses B series	-	-	-	-	5 - 100	P
Ketoses L series	-	-	-	-	5 - 100	P
Conjugated saccharides	-	-	-	-	5 - 100	P
Disaccharides	-	-	-	-	5 - 100	P
Monosaccharides	-	-	-	-	5 - 100	P
Polysaccharides	-	-	-	-	5 - 100	P
Tetrasaccharides	-	-	-	-	5 - 100	P
Hydrazine	-	-	-	-	-	T
Hydrogen peroxide	-	-	-	-	-	T
Quinoline	-	-	<0.5 mg/l ^a	(no odor or visible film)	-	T
Sodium hydroxide	-	-	-	-	-	E
Quaternary ammonium salts	-	-	-	-	-	E
Fluoride solutions	2 mg/l	2 mg/l	-	-	-	E
Potassium permanganate	-	-	-	-	-	E
Sodium hydroxide	-	-	-	-	-	E
Polyacrylates	-	-	-	-	-	E
Inorganic phosphates	-	-	-	no limit	-	E
Organic phosphates	-	-	-	no limit	-	E
Organic phosphonates	-	-	-	-	-	E
Acetate salts of coco amines	-	-	-	-	-	B
Quaternary amines	-	-	-	-	-	B
Octyl phenoxy polyethoxy alcohol	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Octylalkylene sulfated alcohol	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sulfated ester alcohol sodium salt	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Ethylene cycloamido lauryl, 2-hydroxy ethelene sodium alcoholate methylene carboxylate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Modified fatty alkylolamide	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl amido butane	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
n-Octyl butane	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Coconut diethanolamide	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Diethanolamine superamide	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Lauric acid diethanolamine condensate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl aryl polyethenoxy ester	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Alkyl polyethienloxy ethanol	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Polyoxyethelene alkylaryl ether	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Condensation product of ethylene oxide with propylene glycol	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Fatty alcohol alkylamine sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Modified ammonium alkyl sulfate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sodium hydrocarbon sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Sodium lauryl sulfonate	-	-	0.2 mg/l	0.5 mg/l	375 - 1900	S
Antimony	-	-	-	1.0 mg/l	0.05	N/T/G
Arsenic	0.10 mg/l	0.2 mg/l	-	0.1 mg/l	<0.12	N/T/G
Barium	-	-	-	1.0 mg/l	<0.14	N/T/G
Manganese	0.2 mg/l	no limit	-	0.05 mg/l	<0.05	N/T/G
Nickel	0.2 mg/l	-	0.02 x 96-hr. LC50	-	77	N/T/G
Tin	-	-	-	-	<1.0	N/T/C
Vanadium	-	0.1 mg/l	-	-	48	N/T/G

Table V-1
(cont)

SECTION VI
RECOMMENDATIONS

VI. RECOMMENDATIONS

While pollution to surface streams can be detected through stream monitoring and corrected at the source, pollution to underground aquifers cannot be detected so easily nor can pollution once introduced to the aquifers be easily removed. Even continued washing of aquifers, if it were economical or feasible, would be a long term, difficult process to conduct. Therefore, the best way to control pollution of aquifers is to prevent introduction of pollutants.

Our final recommendations are based on our evaluation of hydrogeologic conditions in the project area, our investigations of uranium and petroleum exploration and extraction programs, and our review of pertinent rules and regulations relating to these programs. These recommendations are basically divisible according to three topics - exploration activities, uranium solution mining, and enhanced oil recovery.

REGULATION OF EXPLORATION ACTIVITIES

Widely spaced drill holes resulting from petroleum and uranium exploration have definite potential for ground water contamination. Almost all this potential will be eliminated if abandoned holes are adequately plugged.

Oil Exploration

The Montana Oil and Gas Conservation Commission's Rules and Regulations governing oil well plugging are currently under revision, according to a verbal report from a representative of that body. The present Rules and Regulations do not specify that cement be used to plug abandoned oil wells. However, the Rules are enforced through the requirement of completion by the operator of a form that does specify cement plugs across porous zones and a required amount of cement (Appendix III). We recommend that the revised Rules and Regulations also require cement. We suggest that it be formally specified that cement plugs be adequately placed and monitored with regard to abandoned oil wells. We are aware of situations in other states where cement plugs were not adequately placed at aquifers, others where they reportedly moved downhole, and still others there, through hurrying and/or neglect, some important aquifers were not cemented as required.

We also suggest that two additional procedures be followed. First, only cement that is insoluble in the respective formation water should be used. The cement

industry is quite advanced in this regard, and compositions of cement can be adjusted to be insoluble under almost all chemical ranges of formation waters. Where very corrosive conditions are encountered (e.g. high CO₂ waters), plastic pipe can be used and epoxy can be used to seal the well. Because a very wide range of conditions is possible, the type and density of cement or other plugging material should be specified for each environmental condition. Secondly, some type of long-term monitoring of plugs should be established. These requirements will help to achieve the goal that plugs will be effective indefinitely.

Uranium Exploration

In a manner analogous to that for oil companies, mining companies are required to obtain exploration permits from the Department of State Lands in order to explore in Montana. The department's rules and regulations require that mining companies submit with their applications information regarding number, depth, and location of holes planned, planned access roads, methods of preventing pollution of ground water, and plans for reclamation. This information is evaluated and the permit is granted subject to the mining company's meeting the requirements. The department inspects the reclamation to insure compliance with the permit.

Having been involved in uranium exploration programs, we recognize the potential pollution hazard. However, we also recognize the cost burden of cement

grouting, additional permitting, etc., on the exploration programs. Our discussions with mining company personnel who have worked in Montana reveal that the smaller companies with limited exploration budgets have excluded Montana because of the state regulations. Personnel of larger companies, especially those that are divisions of major oil companies, told us during our interviews that while the permitting process slowed their program, they were prepared to continue and that they have sufficient capital to spend on exploration.

In discussions with personnel of mining companies who have explored in Montana and who have complied with state exploration permits, we learned that the method used to prevent ground water pollution was to fill the drill hole with heavy bentonite fluid and then place a cement plug at the surface.

The Department regulations allow the mining company to choose its method of pollution prevention; department personnel then review this proposal.

We feel that the Department's regulations are generally sufficient, but that more careful evaluation of proposed plugging methods may be necessary.

Appendix I is a copy of the plugging specifications used by Power Resources Corporation in their uranium exploration programs in Colorado, North Dakota, and South Dakota. The available evidence indicates that this hole-plugging procedure, which is modeled after and improves upon that approved by the New Mexico State Engineer

for use in uranium exploration in the San Juan Basin, should be more than satisfactory for the same purposes in Montana.

Therefore, we recommend that the New Mexico regulations serve as a basic regulatory model for those to be applied in Montana, but that Montana include additional detailed descriptions of procedures after those outlined by Power Resources. We propose that the following points be emphasized or amended:

1. Of course, the specification of Baroid products should not be made. Rather, the viscosity of the beneficiated bentonite mixture, its gel strength, and its filtrate volume should be emphasized. These should meet or exceed those provided by the Baroid mixture. However, only the viscosity should have to be measured for each hole and should be 20 seconds greater than that of the drilling mud. Thus, for mixtures developed by other companies, evidence will have to be produced that shows the required viscosity - gel strength - filtrate relationships before they will be acceptable for use. If circulation is lost and a column of mud cannot be maintained, the hole shall be plugged with the cement slurry.
2. Flowing artesian wells should be plugged with a cement slurry of at least 15 pounds per gallon weight.
3. Reports on hole locations, depths, plugging procedure, etc. shall be required and a representative of the state shall be designated and an affidavit filed, as in New Mexico.
4. All holes shall be plugged from the bottom up, except as in #6, below.
5. Seismic holes shall be plugged by running non-metal drill pipe or hose into the hole to point between 15 and 20 feet above the shot depth and then plugged as other holes.
6. Maximum depth of hole not required to be plugged from bottom up is 20 feet.

7. All holes shall be plugged with cement from the ground surface to a depth of 8 feet. If in plowed ground, the top of the plug can be 18" below the ground, with a metal marker to provide for location (See Power Resources procedures).

An optional method of ensuring proper hole plugging is a licensing program for exploration drilling contractors similar to that required of water well drilling contractors. This license would put the responsibility of proper plugging on the drilling contractor or other representative, but someone who is in the best position to see that the plugging is done correctly. The license could require reports to be submitted on plugging and records to be kept by the contractor.

We believe that a careful balance is necessary to allow the exploration companies to seek the needed resource. However, they must recognize their obligation to protect the existing ground water resources. The degree to which this protection is guaranteed must be carefully weighed against the possible decrease in exploration activity and resulting adverse impact on local and state economy.

REGULATION OF SOLUTION MINING

Although solution mining of uranium has been conducted during the last several years, its practicality and effectiveness as a mining technique is still in the testing phase. Its relatively small cost compared to that of underground mining and open pit mining may result in it being a viable mining technique. Consequently it is wise to plan for the possibility that this technique may be used in southeastern Montana.

Expertise Requirements

Solution mining does not require particularly difficult techniques, and it can be safely conducted if the expertise is available to the operator. Solution mining requires a multi-disciplined approach with experts in hydrology, chemistry, water well construction and completion, ground water hydrology, and metallurgy. Presently there are very few groups other than major mining companies and oil companies that have such a diverse team available to successfully accomplish solution mining. Even the majors use consultants in some fields to complete the team. Consequently, to ensure that knowledgeable people are conducting solution mining regulations, you should include a system to evaluate the expertise of solution mining companies.

Hydrogeologic Studies

In order to protect the state's ground water resources, consideration should be given to establishing rules and

regulations within the existing framework of state agencies to require a permit for solution mining. This permit should be issued only after careful investigation.

Submitted with the permit application should be a description of the mining process and a plan for aquifer reclamation. The study should include a determination of the ground water gradient for each aquifer above the solution mining interval and for the shallowest aquifer underlying the interval. The study should also include an evaluation of porosity, permeability, storage coefficient or specific yield, direction of and rate of ground water migration, and the extent of aquifers in the area. The extent and hydrologic characteristics of confining strata need to be determined.

Included in the report on the results of the hydrogeologic study should be a discussion of the relationship between the aquifers and nearby surface water drainage systems as well as the relationship between the aquifers and nearby water supply wells. All water wells within a specified distance should be inventoried with water levels, pumping levels, well yields, well use, and well design all documented. All of the above information is necessary to evaluate the suitability of an area for solution mining.

Permit Procedures

Consideration should be given to requiring proof of competence in solution mining methods and techniques before an applicant is issued a pilot test permit and adequate

testing of a selected ore body should precede the issuance of a mining permit.

This pilot test would be utilized to determine the operator's capabilities to safely conduct solution mining under the specific geologic conditions. It would also allow him to evaluate his process to determine whether or not it would be suitable for the given geochemistry of the area. We also suggest that at the end of the solution mining test the operator be required to reclaim the area to applicable standards to show his capability to reclaim the aquifer. If after the pilot test the operator has shown sufficient competence to successfully complete the mining and reclamation, he then should be granted a permit for a given area and period of time.

Included with the application should be a sufficient amount of engineering data explaining the process to be used for either a pilot test facility or a mining facility. This information should explain the process, the equipment required and the well construction techniques to be utilized. Submitted with the engineering data should be a monitoring program to ensure that the solution mining is carried out safely. This monitoring program would necessarily include monitoring wells to determine whether fluids are escaping from the test site and whether pressure gradients in underlying and overlying aquifers are changing to indicate migration of fluids from one aquifer to another.

The monitoring program should also evaluate whether or not prior exploration drill holes are leaking not only at the surface but between aquifers. Sampling should be done in the production recovery wells to determine whether or not the ions expected to be mobilized are in fact mobilized and those that were not expected to be mobilized are not being mobilized.

The operator should also be required to document emergency procedures that would outline the steps to be taken for a surface spill, leak, flooding or other problems of contamination to either personnel or equipment or the surrounding environment. Emergency procedures for controlling the escape of injection solution to underlying or overlying aquifers should be documented. As a condition of approval, the results of the monitoring program should be routinely submitted to the agency with a narrative analyzing the data.

The application should also include specific alternative methods of aquifer reclamation. The agency should realize that prior to mining, the operator may not specifically know which methods of reclamation would be most suitable. However, if the operator is required to conduct a pilot test with test reclamation, he will then know what methods will be necessary following full scale mining to adequately reclaim the aquifer. The operator should then submit a detailed plan to the agency for evaluation.

Bonding should be required to allow for reclamation of the area should the operator fail to do so for any reason. The amount of the bonding should be sufficient to include the cost of plugging all wells, removal of surface equipment, and reclamation of the affected ground water aquifers. Reclamation of the ground water aquifers would be the most expensive and the most difficult to define. Regulations controlling the solution mining operator should also provide for methods of revocation of permits, fines for infractions, as well as machinery for criminal punishment should the operator fail to comply with regulations.

ENHANCED OIL RECOVERY

Because a foreign chemical is injected into and extracted from a permeable formation in both processes, solution mining for uranium and enhanced oil recovery pose similar problems. However, a basic geologic difference between uranium solution mining and enhanced oil recovery is that oil is a fluid that is stratigraphically or structurally trapped and the permeable reservoir zone is commonly naturally isolated, while uranium roll fronts occur as zones of mineral concentration in commonly nonisolated aquifers that are characterized by through-flowing ground water.

Much higher injection pressures, reaching as high as 3,000 psi., will be subjected to wells involved in enhanced recovery processes. It is thus desirable that more rigorous procedures for monitoring the installation and maintenance of well casings be developed. Similarly, the plugging of wells should be monitored, including the installation of cement mixtures which will be compatible chemically with formation waters. Such compatible cement is not specified in the current regulations. In addition, we recommend that the requirements be initiated for the operators to neutralize contaminated aquifers which occur through faulty procedures that result in casing leaks and other modes of aquifer contamination. Where very corrosive conditions are encountered, for example; involving high carbonate waters, plastic pipe may have

to be specified and epoxy seals used. A very wide range of formation waters is possible and the type and density of cement or other plugging material should be specified for each environmental condition.

The most immediate potential problem related to enhanced oil recovery is that presented by the Bell Creek field micellar-polymer test.

The results of our investigation of the situation indicate that there is little danger of significant ground water contamination from Gary's recovery process as long as they adhere to the regulations and regulatory-agency processes involved. Gary Operating Company is familiar with injection-recovery techniques in the Bell Creek field through their waterflood activities, which they have been conducting for almost 10 years. The chemicals they will be injecting are very expensive, and because it is in their own best interest to achieve maximum recovery, they will undoubtedly take all necessary steps to minimize the loss of solutions while the recovery program is in progress. The Muddy Sand producing zone is deep (4,500 feet) and essentially isolated from important aquifers. Consequently, the greatest potential for ground water contamination will be associated with shallow-aquifer communication due to abandoned wells. It is the same problem of adequate hole-plugging procedures, and our recommendation is to require adequate cementing and monitoring of all wells associated with their process, as discussed in detail above.

MONTANA AGENCIES AND REGULATION

Results of our analysis of Montana water laws suggest that ground water pollution related to uranium and petroleum can be controlled within the framework of existing state agencies. It could probably be controlled without major changes in existing rules and regulations. However, we believe that in order to ensure an efficient evaluation of permit applications, it would probably be necessary to modify statutes as well as rules and regulations to specifically mention solution mining, enhanced oil recovery, and specific procedures to be followed. It also appears that several state agencies could exert control over these activities under present statutes. It will be necessary to define each agency's jurisdiction so that there is no interagency competition that would result in inefficient administration over solution mining.

It appears under the present system that control of these activities is distributed among the Department of Natural Resources, which controls well permits and well construction; the Department of State Lands, which controls mine siting, mine planning, and mine reclamation; and the Board and Department of Health and Environmental Sciences, which controls pollution to state waters. All of these agencies currently have permitting systems and rules and regulations controlling their area of responsibility.

After reviewing a document entitled "Montana Water Pollution Control Systems" prepared for the Montana State Department of Health and Environmental Sciences and a

document entitled "Proposed Guidelines for the Strip Mining, Reclamation Act", 1975, we conclude that both documents outline many of the necessary requirements we believe are necessary items previously mentioned herein to regulate the energy exploration industry. While the regulations from the Department of Health and Environmental Sciences do mention water quality standards, they do not require preparation of a plan for reclamation, nor set specific reclamation standards.

We feel that standards are necessary to ensure protection of the State's aquifers. These standards should be carefully thought out and should be based on a classification of the State's aquifers with regard to use and quality. Without a classification system based on existing quality, an operator may be required to restore the aquifer to a better condition than that prior to mining. It is entirely possible that in some areas, aquifer reclamation may not be necessary because its poor water quality precludes its use as a water supply in the future. Methods for determining the class of each ground water aquifer should be outlined in the rules and regulations; minimum standards of reclamation for each quality of water should be set by the regulations. Neither of the two reviewed documents discusses a monitoring program in detail. Also, they do not indicate the types of material to be monitored or monitoring frequency. We believe that the regulations should set standards for frequency and method of monitoring.

Regulations ultimately established should be parallel for all operators involved in all drilling-based exploration and development methods. Because the Department of State Lands controls all other mining methods and reclamation it is logical for them to control solution mining. On the other hand it is the responsibility of the Department of Health and Environmental Sciences to control pollution to the State's waters; they, therefore, would be involved in enhanced recovery as well as solution mining. The Department of Natural Resources, which controls well drillers and well construction, would also necessarily be involved. Assuming that the existing framework continues, these agencies must determine their areas of responsibility to prevent unnecessary duplication of effort.

We expect that one of these three agencies would be selected as the lead agency with primary control over solution mining and enhanced oil recovery. The other two agencies could serve as advisors to the lead agency to analyze applications and set conditions for granting permits.

Because solution mining and enhanced oil recovery involve an interdisciplinary technology, the review must be an interdisciplinary evaluation. Expertise will be required in well construction, metallurgy, ground water chemistry, ground water hydrology, environmental sciences, and reclamation. Until these activities become sufficiently common to warrant the cost of full-time, qualified personnel

to provide adequate review, it might be wise to allow the agencies to retain outside consultants to aid in the evaluation of permit applications. This has been done successfully in other states.

SECTION VII

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

VII. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The principal purpose of our investigation was to determine the potential for ground water contamination in the project area due to the activities related to the extraction of and exploration for petroleum and uranium, and to develop recommendations for the prevention of future contamination. Meetings with the project staff concerning results obtained during the early stages of the study led to the agreement that our principal emphasis of investigation should focus on problems related to uranium exploration, uranium solution mining, and enhanced oil recovery. All these activities represent significant ground-water pollution potential in the study area.

Uranium exploration presents a potential problem because uranium occurs at relatively shallow depths and in those formations which are the principal aquifers in much of the area. Numerous drill holes are required to close in on the uranium roll-fronts, along which the ore typically occurs in pods normally only a few tens of feet wide. Consequently, the vast majority of exploration holes do not encounter ore and are abandoned. Plugging procedures for these holes are not currently standardized or sufficiently regulated. We recommend such a procedure and include specific details, with regulatory options. Basically, the recommendations involve plugging all exploration holes from the bottom up with, as a minimum,

beneficiated bentonite mud with specified, measured, documented, and inspected properties. We recommend similar procedures for seismic drill-hole plugging, and suggest the use of cement that is chemically compatible with the respective formation waters under some circumstances.

Uranium solution mining presents special problems because a chemical that will "leach" the uranium from the ore zone will be injected into an aquifer. Numerous wells only a few tens of feet apart will be required. Specific safeguards to ensure that injection and recovery wells do not leak and are adequately plugged when abandoned, that the injected chemicals are totally recovered or neutralized, and that the aquifer is restored and monitored, are suggested. These safeguards include satisfactory test procedures, and preliminary follow-up hydrologic analyses.

Enhanced oil recovery is similar to uranium solution mining in that foreign chemicals are injected into the subsurface and recovered. It is different because oil is typically "trapped" by various types of natural geologic barriers that prevent its migration. Thus, the oil-recovering chemicals are not normally injected into an aquifer with through-flowing ground water. The oil reservoirs in the area are thousands of feet deep. The greatest pollution potential from enhanced oil recovery comes from well casing leaks, spills that may reach aquifers, and inadequately plugged wells.

Like solution mining for uranium, the chemical technology of enhanced oil recovery pollution is insufficiently developed to evaluate all the possible ramifications of pollution to ground water; unlike solution mining for uranium, the injection-recovery processes are well-tested. The toxic, carcinogenic or other harmful effects of the chemicals and their synergistic products most recently developed and tested for enhanced oil recovery purposes are largely unknown. However, the high costs of many of these chemicals, now and for greatly increased oil prices, prohibit their widespread use and promote their control and conservation during use. Based on these and other factors, we recommend that rigorous plugging and monitoring specifications be developed for enhanced oil recovery, including the use of casing and cement plugs that are chemically compatible with formation waters, hydrogeologic system evaluations, monitoring, and aquifer restoration when necessary.

There is hardly anyone who does not recognize that energy-resource exploration and development are desirable and necessary activities, or that our aquifers need to be protected by those exploring for energy. Such protection will only occur through the development and enforcement of fair, reasonable, enforceable, and practicable regulations that protect the public interest. Such regulatory functions should be the responsibility of different governmental agencies, according to their different areas of expertise. However, because many of the problems involving ground

water pollution from energy-resource activities are similar or the same, there is logically some subjectivity as to the potentially most efficient method of governmental regulation.

Our review of the regulations governing the exploration and development of both uranium and oil indicate that they are currently not adequate for all possible contingencies and problems related to the future of solution mining and/or enhanced oil recovery in the project area. There is overlap among the agencies concerned with ground water pollution and no agency has sufficiently extensive control, without the possibility of usurping the functions of some other agency, to oversee these activities. In addition, some significant aspects of these energy-resource activities are not currently considered by any agency. Therefore, we recommend the following:

1. That one set of regulations be developed for those activities related to uranium exploration and development and another for those activities related to oil exploration and development.
2. That one agency be designated to adopt and enforce those regulations pertaining to uranium and another those pertaining to oil.
3. That the regulations adopted be reasonable, enforceable by the appropriate state agency involved, and still be practical for the development of the energy resource without unreasonable cost or requirements on the part of the company.

4. That specific procedures and requirements for the plugging of exploratory drill holes for uranium be adopted, commensurate with our recommendations set forth in this report.
5. That specific procedures and requirements for cementing and the type of cement of drill holes related to uranium solution mining and enhanced oil recovery be adopted according to the specifications as set forth in this report.
6. That sufficient time be allotted those companies exploring for uranium so compliance with any rules and regulations governing their exploration activity is possible.
7. That compliance with the adopted regulations be subject to that geologic information in existence and that new information will not have to be developed before exploration can begin.
8. That the permit procedure be sufficiently streamlined and efficient so it does not prevent exploration in Montana.
9. That the regulations be provincial where appropriate. As an example, exploration in artesian aquifers should not be automatically subject to the same hole-plugging requirements as exploration in unconfined aquifers.

With adequate planning and review to establish and ensure that geologic and hydrologic conditions are amenable to the extraction of these resources, disturbance of the ground water system and the risk of pollution can be minimized. However, regulations involving the entire spectrum of processes of exploration and development are currently inadequate and need to be updated to ensure the adequate protection of aquifers.

We believe that the state agencies can, through their statutory mandates, administer proper regulations concerning these energy-resource activities. However, there is apparent duplication of responsibility of regulatory authority which needs to be eliminated. We believe also that one agency should be designated as the lead agency to prepare rules and regulations to govern solution mining. The present regulatory process for oil exploration and development will basically suffice for the enhanced recovery techniques of the future, but additional safeguards involving the ground-water pollution potential of this method are recommended.

The public is generally not aware that ground water normally does not occur in underground streams nor does it flow at great velocities over large distances. We expect that this lack of knowledge will create general unfounded public concern that activities involving aquifers affected by uranium and oil exploration and development in the Yellowstone-Tongue project area will constitute

severe ground-water pollution hazards. This will not necessarily be the case. Most pollution to aquifers will generally be confined to a small area, will migrate at a slow rate, and will not likely be severe or uncontrollable. It remains only for the state of Montana to develop regulations affecting both uranium and petroleum activities that consider problems of reclamation, problems of adequately evaluating the hydrogeologic system, the operator's capabilities to conduct the operation successfully, safely, and without polluting, and the need for adequate monitoring. The regulations should protect the public's interest, while at the same time, provide a favorable climate for exploration and development of these energy resources.

APPENDIX I
DRILL HOLE ABANDONMENT PROCEDURES

APPENDIX I

DRILL HOLE ABANDONMENT PROCEDURES

by

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DRILL HOLE ABANDONMENT PROCEDURE

The abandonment procedure outlined below is used by Power Resources Corporation when drilling shallow exploration holes (less than 700 feet) in formations where artesian water is not encountered. It was first developed and accepted in New Mexico by the State Engineer, and it has been adopted for general use in Colorado where the Laramie Formation and Fox Hills Sandstone are being drilled for uranium. Tests in these areas have shown that the Quik Trol - Quik Gel mud (or the new bentonite-polymer mixture) permanently protects the aquifers and confines their waters. Where holes have been drilled on close spacing for solution mining, injected water was not "lost" to holes filled with this mud.

Power Resources Corporation is requesting that this abandonment procedure be accepted for shallow holes drilled into the Sentinel Butte, Tongue River, and Ludlow Formations in the southwestern part of the Williston Basin of North Dakota and South Dakota. Artesian aquifers will be cemented as required by existing regulations. We have no plans to drill where artesian water is known to exist in the Williston Basin, but if artesian water is encountered, we will fill the hole with cement from the total depth to a point six feet below the surface.

Purpose: This procedure is intended to standardize the method for abandonment of shallow drill holes (less than 700 feet) and particularly to ensure that ground water is permanently confined to natural aquifers.

Responsibility: It is the responsibility of the geologist supervising the drill rig to ensure proper implementation of this procedure.

Materials:

Baroid Products

Quik Gel - A high-yield bentonite packaged in fifty (50) pound bags.

Quik Trol - Granular, nonfermenting organic polymer packaged in two (2) pound moisture-proof bags.

A new product, developed by Baroid especially for conditioning and abandoning mineral exploration drill holes, is a premixed combination of high-yield bentonite and nonfermenting organic polymers. This new product has been tested in drill holes with aquifers at depths as much as 2800 feet in New Mexico with complete success.

Equipment:

Mixing tank - Most drill rigs used in shallow exploration drilling have steel mud pits which are used for containing the circulation fluid. These pits vary in volume from 40 to 60 cu. feet, and it requires 13 cu. feet of mud to fill 100 feet of hole (5").

Jetting equipment for mixing - As illustrated on the attached sketch (Figure 1), the mud can be mixed thoroughly with specially designed jetting equipment.

Marsh funnel and graduated container - The funnel is screened and designed to measure viscosity (see attached illustration).

Mixing:

- A. At the time of reaching total depth, the proper ratio of Quik Gel and Quik Trol are premixed (dry) prior to "jetting" into the mixing tank (this is not necessary when the new premixed product of Baroid is used). One (1) pound of Quik Trol to 50 pounds of Quik Gel is the proper ratio.
- B. Before mixing the bentonite-polymer powder into the drilling fluid, the viscosity of the drilling fluid must be measured as follows:
 1. Hold or mount the Marsh Funnel Viscrometer (Figure 2) in an upright position and place a finger under the outlet to seal it.

2. Pour the test sample, freshly taken from the mud system, through the screen in the top of the funnel until the level just reaches the under side of the screen.

Note: When measuring the viscosity of the mud with new additives as described below, lumps may be present. These should be screened out and discarded.

3. Immediately remove the finger from the outlet tube and measure the number of seconds for a quart of mud to flow into the measuring cup.
4. Record time in seconds as "funnel viscosity." Note: Calibration time for fresh water at 70° F is 26 seconds.
5. The funnel viscosity measurement obtained is influenced considerably by the gelation rate of the mud sample and its density. Because of these variations, the viscosity values obtained with the Marsh Funnel cannot be correlated directly with other types of viscometers and/or rheometers. The 1000cc. measuring cup, graduated in cubic centimeters and fluid ounces, is designed specifically for use with the Baroid Marsh Funnel Viscometer. A quart volume is clearly marked on the measuring cup.

The viscosity of the drilling fluid should be recorded on the drill hole abandonment report form (see form attached).

- C. The mixing of the bentonite-polymer into the drilling fluid must be done slowly and thoroughly, "balls" of unyielded gel floating in the mixing tank is an indication of mixing which is insufficient and/or too rapid. For a 4 3/4" diameter drill hole, the volume of mixed gel required is 13 cu. feet per 100 feet of depth. To

minimize waste, a portion of the mixing tank equivalent in volume necessary to fill the drill hole should be blocked off and the mixing operation confined to that portion. In most cases, one bag (50 pounds) of Quik Gel added to half a bag (one pound) of Quik Trol will fill a 300 foot hole with the most effective mud mixture.

D. When the hole abandonment mud appears to be correct, its viscosity should be measured. Empirical evidence based on hundreds of holes drilled and plugged in New Mexico has shown that the mud viscosity should be increased by 20 seconds on the Marsh Funnel Viscometer to meet requirements set by the New Mexico State Engineer. These requirements are:

1. A filtrate of less than 13.5 ml. lost over a cross sectional area of 7.1 sq. in. in 30 minutes with a pressure of 100 psi. at room temperature.
2. A ten-minute gel strength of 20 pounds per 100 sq. feet.

The procedure which is used in New Mexico includes a lab analysis of the abandonment mud to determine if the above requirements are met. Almost without exception these requirements are met for holes in which the mud viscosity was raised 20 points above that measured as the hole reached total depth. If the drilling fluid has 35 seconds viscosity, it should be raised to 55 seconds viscosity with bentonite-polymer additives. If, on the other hand, the drilling fluid is essentially fresh water (26 to 28 seconds viscosity) it need only be raised to 48 seconds viscosity with the bentonite-polymer additives to meet the requirements established in New Mexico.

These specific requirements have not yet been established in Colorado, South Dakota, or North Dakota where Powerco has drilling operations at present. We require that the viscosity be raised at least to 53 seconds on the Marsh Funnel Viscosimeter or to 20 seconds above the viscosity of the drilling fluid, whichever is the greater. Our procedure usually exceeds the increase found to meet the requirements of New Mexico.

The viscosity of the mud after conditioning for abandonment is measured and this is recorded on the drill hole abandonment report form.

Injection: After determining that the mud meets specifications, the mud is pumped into the drill hole displacing the fluid already in the hole. It will be apparent when this has been accomplished by watching the returns from the hole. The mud should not be "pumped around" several times, as this will change the character of the mixed gel and necessitate retesting. The drill pipe may now be removed from the hole and whatever uninjected mixture remains used to fill the hole to the plug level (10 feet below surface) after the pipe is finally withdrawn.

Plug: After injection of mud it is necessary to emplace a substantial surface plug as follows:

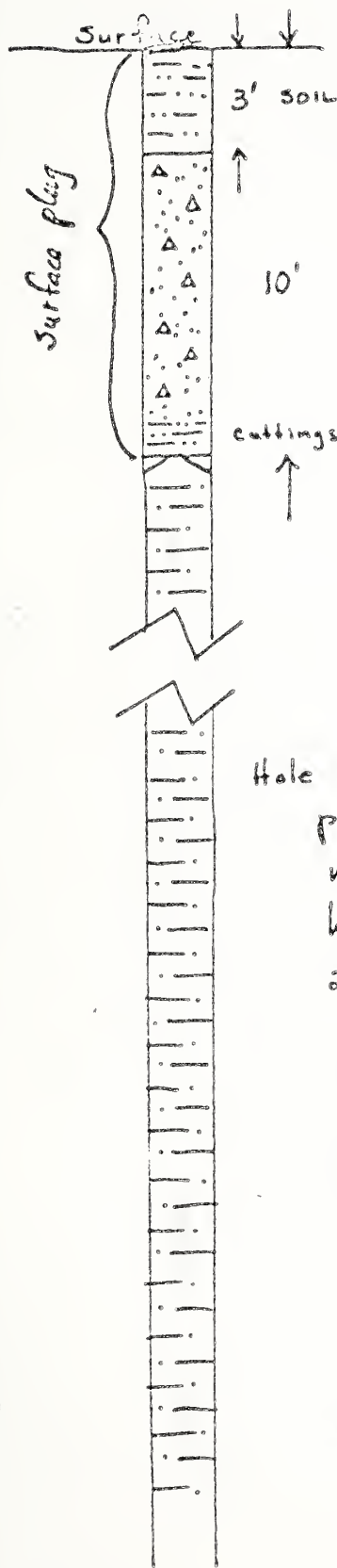
1. Place ocotoplug or other substantial expandable plug in drill hole to depth of ten feet.
2. Shovel about one foot of drill cuttings into the drill hole to act as a sealant for the cement.
3. Empty at least 1/3 of a bag of cement into wet, sandy part of drill cuttings pile. Note: The drillers are requested to shovel the

sand and gravel cuttings into a separate pile to improve the quality of the cement plug. If the hole is out of gauge, such as in a surface gravel, then more cement-sand mixture must be placed in the hole. If necessary, several sacks of cement will be used to plug one hole.

4. Using shovel, thoroughly mix cement and sand until all cement has been taken up by the wet sand. Add water from separate containers if necessary.
5. Shovel mixture of sand and cement into the drill hole.
6. Lightly tamp mixture in hole to ensure against air pockets forming.
7. Repeat above procedure until hole is filled with cement to a point about three feet below ground level.
8. Shovel cuttings into hole to fill it up to slightly above ground level. This will allow for some compaction.
9. Place a wooden stake in the hole with the proper drill hole number affixed to it. The stake should not protrude more than two or three inches above ground level. In areas where wooden stakes protruding above the surface are undesirable, 6" lengths of 3/8" steel rebar or other substantial pieces of metal should be placed at top of cement column. This will allow later hole location by means of a metal detector.

Reclamation: The final step in the hole abandonment procedure is the reclamation of the surface around the hole. After a few weeks the cutting piles are fairly well dried out so that it is possible to spread the cuttings into a thin layer. The U.S. Forest Service recommended that for best results, the piles should be reduced to a veneer less than 1/2" thick. This depth will allow the underlying grass to quickly grow

up through the cuttings. In some areas it is desirable to disk or rake the cuttings to facilitate revegetation. If large percentages of clay are present in the cuttings, it is sometimes necessary to remove them to a disposal area. This is usually an abandoned gravel pit or a pit dug for this purpose.



Octoplug, spider plug or
other expanding plug
10' below surface,
1' cuttings above plug
6' cement plug to about
3' below ground surface.

Hole filled to base of surface
plug with gel-polymer
mud. This mud must
have viscosity more than
20 seconds on Marsh
Funnel Viscometer higher
than drilling mud. It
consists of high-yield
bentonite with ~~or~~ nonfermenting
organic polymer additive

If water-bearing horizons with
~~to~~ artesian flow are encountered,
the entire hole is filled with cement
to a point 6 ft below surface.

APPENDIX II
NEW MEXICO HOLE-PLUGGING PROCEDURE

NEW MEXICO HOLE-PLUGGING PROCEDURE

1. Drill holes that are not plugged with cement shall be plugged to the land surface at the time of abandonment with drilling fluids which meet the following specifications:

- (a) ten minute gel strength of at least 20 lbs./100 sq. ft.; and

- (b) filtrate volume not to exceed 13.5 cc.

The above properties shall be determined in accordance with RP 13-B, Sections 2 and 3, (low temperature test), respectively. Standard Procedure for Testing Drilling Fluids, Third Edition, February 1971, American Petroleum Institute. The tests shall be conducted on a drilling fluid sample taken at the hole collar after the total depth of the hole has been reached and all circulation has been completed. A cement plug may be used at the surface for a top cap.

2. The weight of the drilling fluid left in the drill hole at the time of abandonment shall be sufficient to prevent flow of water into the hole from any aquifer penetrated. In the alternative drill holes may be plugged bottom to top with a neat cement slurry weighing not less than 15 lbs. per gallon: the weight of the neat cement shall be sufficient to prevent the flow of water into the hole from any aquifer penetrated.
3. In lieu of direct supervision of the plugging of drill holes by State Engineer Office personnel, the State Engineer may designate as his representative a person who is an employee of the person, firm, or corporation

for which the drilling is done, whether under contract or otherwise, and whose qualifications for such designation are acceptable to the State Engineer. Any person seeking to be so designated may file with the State Engineer a statement of his position of employment and qualifications.

4. It shall be necessary to report on each hole as provided for in Section 63-2-3.3, NMSA, 1953 and Article 4-21.1 of the State Engineer's rules and regulations. For a hole drilled in this area, it will not be necessary to submit a log if the hole is abandoned as described in 2 and 3 above. A part of such report shall be a sworn affidavit of a person designated as the State Engineer's representative attesting from his own knowledge to the aforementioned properties of the drilling fluid left in the hole and as to whether or not the hole flowed at the surface. If the hole is plugged with a cement slurry, the affidavit shall so state and attest to the weight of the cement slurry used.

If more than one hole is drilled under the supervision of the same designee and the plugging of each hole meets the specifications cited above, then only one affidavit will be required relative to reports submitted at any one time.

5. These adopted procedures do not release any person, firm, or corporation drilling a mine drill hole or a mine lode discovery hole more than 10 feet in depth which encounters

water from the responsibility of submitting reports on all such holes drilled subsequent to the effective date of Section 63-2-3.3, NMSA, 1953.

6. The person, firm, or corporation for which the hole was drilled shall maintain a record of each drill hole, which record shall include the method of plugging and the properties of the drilling fluid or cement left in the hole. Such records shall be available for review by the State Engineer.

APPENDIX III
MONTANA OIL WELL PLUGGING FORM

RECORD OF PLUGGING INSTRUCTIONS

Company: _____

Well Name and Number: _____ Total Depth _____

Location: _____ Sec. _____ Twp. _____ Rge. _____

Person Requesting Plugging Approval: _____ Date _____

Plugging Orders, Issued by: _____

<u>Formation</u>	<u>Plug Interval</u>		<u>No. Sacks</u>
	<u>Top</u>	<u>Bottom</u>	

Base of Surface (Half in - Half out)

Top of Surface

Erect Marker _____ Cut off below plow depth _____

Plugging Witnessed by: _____ Date _____

Remarks _____

Minimum Plugging Requirements:

No open hole plug less than 25 sacks. Cement plugs across all porosity zones, not between zones. A spacer plug shall be placed between plugs if interval exceeds 2500'.

Hole Capacities
(Feet of fillup per sack cement)

4" - 12.6 Ft.	8" - 3.15 Ft.
5" - 8.06 Ft.	9" - 2.50 Ft.
6" - 5.60 Ft.	10" - 2.00 Ft.
7" - 4.11 Ft.	

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